MEDICAL DEPARTMENT
UNITED STATES ARMY
IN WORLD WAR II

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NOTE

This volume was writtten and edited under the direction and supervision of Colonel John Boyd Coates, Jr., MC, USA, former Director and Editor in Chief, The Historical Unit, U.S. Army Medical Service.

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Colonel, Medical Corps,
Editor in Chief.

MEDICAL DEPARTMENT, UNITED STATES ARMY

SURGERY IN WORLD WAR II

THORACIC SURGERY

Volume II

Prepared and published under the direction of
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THORACIC SURGERY

Volume II

MEDICAL DEPARTMENT, UNITED STATES ARMY

The volumes comprising the official history of the Medical Department of the U.S. Army in World War II are prepared by The Historical Unit, U.S. Army Medical Service, and published under the direction of The Surgeon General, U.S. Army. These volumes are divided into two series: (1) The administrative or operational series; and (2) the professional, or clinical and technical, series. This is one of the volumes published in the latter series.

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746-941v—65——2

Foreword

The first volume on thoracic surgery in the history of the U.S. Army Medical Department in World War II was published in 1963. This is the second and final volume of that special series.

In addition to administrative considerations, the first volume set forth the routine of management of chest injuries from emergency care on the battle field to final rehabilitation in a chest center. It dealt with special types of wounds and with complications only incidentally. This second volume deals in detail with both of those subjects, both of which deserve most careful attention, for many of the concepts set forth were unknown in World War I and in civilian thoracic surgery and were recognized for the first time in World War II.

The syndrome of the wet lung, for instance, undoubtedly existed in World War I, but it went unrecognized and untreated, and its sequelae—often its lethal sequelae—were massive atelectasis and pneumonitis. Yet, once the existence of the syndrome was recognized and its pathophysiology elucidated, its prevention became a relatively simple matter and its management almost equally simple.

Similarly, hemothorax undoubtedly existed in World War I, but again its importance in military surgery was not realized, and such concepts as were developed about it were later proved to be fallacious. Correct management—that is, simple aspiration of the chest—did not always prevent organization of the retained blood and did not always prevent infection of the organizing clot, or even hemothoracic empyema, but it usually aborted most of these pathologic processes. If organization of the clot did occur, decortication was the solution of the problem of infection and hemothoracic empyema. The chest cripples after World War I were happily absent after World War II.

The results achieved in these potentially dangerous complications of chest trauma as well as in foreign bodies retained in the lung, the heart, and the great vessels, constitute a record of real brilliance. Exactly how brilliant it was is evident in the final chapter of this volume, in which there appears the record of a really unique endeavor, the followup, in 1960–61, of a small group of casualties who sustained their chest injuries in 1943–45. The series is small, it is true, but there seems every reason to assume that the excellent status of this small group, whose wounds were truly critical, is an index of the status of most other casualties whose wounds were similarly critical.

Once again, as in the first volume of the series, I would express my thanks to the authors and editors whose devoted work has made possible the production of this and other volumes of the history of the U.S. Army Medical Department

in World War II. And also, as in the first volume, I would pay particular tribute to the fine work of Dr. Frank B. Berry, Editor for Thoracic Surgery, whose enthusiasm, patience, and wise guidance carried this project past its initial difficulties and discouragements to a highly successful conclusion.

LEONARD D. HEATON,
Lieutenant General,
The Surgeon General.

Preface

As was pointed out in the first of the two volumes which make up the thoracic surgery series in the history of the U.S. Army Medical Department in World War II, the fact that the story could not be told in one volume is a reflection of how this specialty came of age in the Second World War.

The first of the thoracic surgery volumes includes a historical note; the general, including the statistical, background of thoracic injuries; administrative considerations in the Mediterranean and European theaters and in the Zone of Interior; and the routine of management of war wounds of the chest from emergency care on the battlefield to rehabilitation in a thoracic surgery center.

This second volume deals with the special types of thoracic wounds caused by the missiles of modern warfare and with the management of their complications. As noted in volume I, the Pacific experience will be related in the volume dealing with surgery in the Asiatic-Pacific theater.

Special attention is devoted in volume II to certain complications of these injuries whose significance was realized, or fully realized, for the first time in World War II.

Retained foreign bodies have always constituted a fascinating phase of military chest surgery, though their management has not always been as discriminating, and therefore as successful, as it eventually became in this war. The series of 134 operations performed by Lt. Col. Dwight E. Harken, MC, in which foreign bodies were removed from the heart and great vessels, constitutes a remarkable achievement. There were no deaths in the series, and all of the patients left the chest centers with normally functioning hearts. The cardiac and cardiovascular operations performed at this and other chest centers during the war helped to lay the foundations for the almost miraculous advances in this field since the war.

The concept of wet lung was developed in World War II by Maj. Thomas H. Burford, MC. The methods devised to combat it prevented graver subsequent complications of chest wounds. As a result, the huge morbidity that had attended these injuries in World War I was eliminated, and many lives were undoubtedly saved.

Hemothorax was recognized in World War II as one of the important complications of chest wounds and as an antecedent of the more serious complications of organizing and infected hemothorax and hemothoracic empyema. Prompt and adequate aspiration of the chest was a simple and uniformly applicable measure of management that eventually came into general use.

Decortication proved the solution in patients with hemothorax which went on to organization and infection because of bad management, or in spite of sound management. The operation had been employed earlier for the type

of empyema usual in civilian life, but not for complications of wounds of the chest. Its bold and imaginative application to organized hemothorax and hemothoracic empyema by Major Burford was attended with such good results that the operation promptly came into general use throughout the theater.

It is a tribute to the excellent quality of the chest surgery done overseas that, after the first months of the war, relatively little active treatment was required by the thoracic casualties evacuated to Zone of Interior hospitals. The thoracic cripples who thronged these hospitals after World War I were almost never observed in World War II.

By tradition, a history of military medicine in any particular war has ended with the end of the fighting. There have been almost no attempts to determine the postwar results of special methods of treatment. Particular attention is therefore directed to the final chapter in this volume, which deals with the clinical and roentgenologic followup, in 1960 and 1961, of 167 casualties who sustained chest wounds in the 1943–45 period. The recorded data represent an incredible amount of time and effort on the part of many persons and agencies, but the followup was entirely the inspiration, and chiefly the work, of Dr. Lyman A. Brewer III, formerly Maj., MC. It was a practical effort because the groundwork for it had been laid during the war: While Dr. Brewer was serving as a thoracic surgeon with the 2d Auxiliary Surgical Group in the Mediterranean theater, he kept an individual record for each casualty he cared for personally. The selection of the patients whom it was considered practical to followup in 1960 and 1961 was made from this material.

This long-term followup study is a unique and praiseworthy endeavor. It is unfortunate that more such attempts have not been made. The excellent clinical and roentgenologic status of these casualties and their active engagement in the normal activities of civilian life give testimony, as Dr. Brewer concludes, to the management of critical thoracic wounds during World War II by the policies and practices described in these two volumes.

As was pointed out in the preface to the first of these two volumes, it would be impossible to produce books of the range of these volumes on thoracic surgery without the painstaking and devoted assistance of a great many persons and agencies. In the end, for a variety of reasons, the chief responsibility for the preparation of this material fell upon a relatively small number of authors. It is a pleasure again to make acknowledgment to them:

Dr. Brian Blades (formerly Col., MC), Consultant in Thoracic Surgery to The Surgeon General and Chief, Thoracic Surgery Section, Walter Reed General Hospital, Washington, D.C., during World War II.

Dr. Brewer, who served with Team No. 2, 2d Auxiliary Surgical Group, in the Mediterranean theater and later in the European theater.

Dr. Burford, who served with Team No. 3, 2d Auxiliary Surgical Group, in the Mediterranean theater.

Dr. B. Noland Carter (formerly Col., MC), Assistant Director, Surgical Consultants Division, Office of The Surgeon General. Dr. Carter, in addition

to preparing the chapters which carry his name, reviewed the entire manuscript and made many helpful suggestions.

Dr. Michael E. DeBakey (formerly Col., MC), Chief, General Surgery Branch, Surgical Consultants Division, Office of The Surgeon General, and now Chairman of the Advisory Editorial Board for Surgery.

Dr. Harken, Regional Consultant in Thoracic Surgery to the Senior Consultant in Surgery, European theater. Dr. Harken also directed the chest center at the 160th General Hospital, Stowell Park, Gloucestershire.

A large part of the artwork was Dr. Brewer's original conception, and he directed the preparation of all of it from beginning to end.

Mr. Milton C. Rossoff, formerly Assistant Chief, Statistical Analysis Branch, Medical Statistics Division, Office of The Surgeon General, collected and tabulated the official statistics for the thoracic surgery volumes.

My grateful appreciation is due to Mrs. Ethel Bauer Ramond, who served as assistant to the Associate Editor and who typed the entire original manuscript with notable speed, accuracy, and real medical intelligence.

Grateful acknowledgment is also due to a number of the personnel of The Historical Unit, U.S. Army Medical Service:

Maj. Albert C. Riggs, MSC, formerly Chief, General Reference and Research Branch, and Mrs. Esther E. Rohlader, Assistant Chief, provided much of the basic data for these volumes and patiently and efficiently answered endless queries and tracked down numerous obscurities to their final solution.

Mrs. Pauline B. Vivette, Assistant Chief, Editorial Branch, prepared both volumes for publication and, with the assistance of Mrs. Martha R. Stephens, Editor (Printed Media), prepared the artwork and its layouts in editorial style for the printer.

Mrs. Hazel G. Hine, Chief, Administrative Branch, handled the multiple details connected with the preparation of volumes issued under Government auspices and also supervised the final typing of the manuscript.

Finally, a special word of appreciation is due to two other persons who worked on these volumes:

Miss Elizabeth M. McFetridge, Associate Editor for the surgical series of volumes, who, after many discouragements, was able to bring together the material prepared by the group of thoracic surgeons who worked in the Mediterranean and European theaters and to prepare it for publication.

Col. John Boyd Coates, Jr., MC, former Director, The Historical Unit, U.S. Army Medical Service, and Editor in Chief of the history of the U.S. Army Medical Department in World War II. Colonel Coates, who served in World War II as Executive Officer, Medical Division, Third U.S. Army, saw the unfolding of the story of thoracic surgery in the European theater and, during the campaign, was in frequent contact with the Consulting Surgeon, Sixth U.S. Army Group. His firsthand knowledge has been useful, and his cooperation in all the work on these two volumes has been most helpful.

FRANK B. BERRY, M.D.

Contents

Part III

OBSERVATIONS ON WOUNDS AND DISEASES OF THE CHEST IN THE ZONE OF INTERIOR

Illustrations

Color Plates

Tables

Part I

SPECIAL TYPES OF WOUNDS OF THE CHEST

CHAPTER I

Special Types of Thoracic Wounds

Lyman A. Brewer III, M.D., and Thomas H. Burford, M.D.

WOUNDS OF THE CHEST WALL

The simplest form of chest wound, the type which involved only the thoracic wall and produced no bony or visceral injuries (fig. 1), always had one serious possibility: The pain which followed might cause voluntary restriction of respiration and of the cough reflex, which, in turn, could cause retention of secretions and introduce the problems of wet lung. Injuries which involved only the soft parts, such as abrasions and lacerations, were usually not serious. Those associated with fractures of the ribs could be serious. Contusions of the chest wall could also be serious.

An occasional patient who seemed to have only a simple contusion of the chest wall developed pleural effusion, apparently because the pleura had shared in the trauma. In these cases, which were usually diagnosed as traumatic

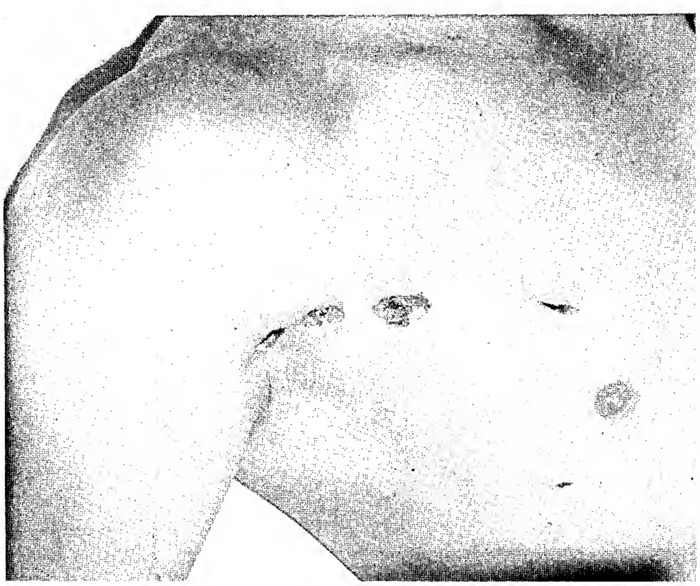

FIGURE 1.—Superficial bullet wounds of chest wall not involving bony structures.

pleuritis with effusion, the fluid was straw colored or amber and had the characteristics of a transudate. Repeated aspiration was usually the only treatment necessary, but in an occasional case, in which the pleural fluid had a high fibrin content, clotting occurred, and the total picture was suggestive of clotted hemothorax. If the condition remained static, decortication might be necessary.

Contusions of the chest wall were also responsible for some intrathoracic hematomas (p. 165).

Case History

The following case history illustrates the intrathoracic complications that sometimes followed a wound of the chest wall not, in itself, of major importance:

Case 1.—This casualty was picked up by aidmen between 1 and 2 hours after he was wounded by shell fragments in the right shoulder and left knee. When he was received in an evacuation hospital 11 hours after wounding, he was found to have a perforating wound of the right upper chest, associated with a moderate hemothorax. Wet lung was demonstrated clinically by many loud rales and rhonchi and was confirmed by roentgenograms. Roentgenologic examination also showed comminuted fractures of the posterior portion of the second and third ribs, and possibly of the fourth rib, on the right side. No foreign bodies were visible on this roentgenogram nor on the roentgenogram of the left knee, which showed an epiphyseal fracture of the tibial tubercle.

Fourteen hours after the patient's admission to the hospital the wound of entrance just below the outer third of the right clavicle was widely debrided under local analgesia, and a large amount of clotted and liquid blood was evacuated. A small fragment of the fractured right clavicle was removed. The wound was sprinkled with powdered sulfanilamide, and a petrolatum-impregnated gauze dressing was applied. Paravertebral nerve block with procaine hydrochloride was carried out at the level of the seventh cervical vertebra and the first through the fourth thoracic vertebrae. The hemothorax was aspirated through the seventh intercostal space in the posterior axillary line, and the 500 cc. of blood thus obtained was used as an autotransfusion, with 500 cc. of physiologic salt solution. Bronchoscopy was employed to clear profuse secretions from the tracheobronchial tree. The wound of the left knee was debrided.

The postoperative course was satisfactory for the first 4 days. Then paravertebral block had to be repeated because of pain. No fluid was found in aspiration at this time. On the eighth day, 1,350 cc. of bloody fluid was aspirated from the right chest. Repeated aspiration on the 10th day produced 150 cc. of thick, pinkish fluid, and on the 12th day, 725 cc. of thin fluid of the same color was removed. Thereafter the chest was dry.

When the patient was evacuated on the 22d postoperative day, he had entirely recovered from his chest injury, but he still had some loss of function of the upper right arm.

Comment.—Contusion of the chest wall was present to some degree in all injuries of the chest in which direct violence was a factor. It undoubtedly played a part in the case just recorded, helping to produce both wet lung and hemothorax. There was no direct communication between the pleural cavity and the wound of the chest wall.

Although this patient had an extensive wound of the chest wall, with hemothorax and wet lung, there was no indication for formal thoracotomy. The infection in the chest wall was controlled by adequate debridement. The lung was expanded by needle aspiration of the blood in the pleural cavity, thus increasing the vital capacity, and intercostal nerve block allowed the patient to breathe deeply and cough effectively with relief of the wet lung syndrome.

SUCKING WOUNDS

General Consideration

A sucking wound (fig. 2) is defined as a wound in which there is more or less free interchange of air through the wound between the pleural cavity and the outside atmosphere. The term, as pointed out elsewhere (vol. I), is both unsuitable and misleading, and blowing wound is preferable nomenclature. Sucking wound, however, has the sanction of usage, and for that reason, its use is continued in this volume.

Potentially, if not actually, all penetrating and perforating wounds of the chest observed in World War II were sucking wounds. A sucking wound sometimes sucked (blew) constantly and sometimes only when the skin and muscle planes were in a certain alinement. The regional anatomy frequently determined whether or not a wound sucked. Generally speaking, a large wound was more likely to suck than a small wound, but size was not the most important determining factor. A relatively small wound in the anterior chest wall, 2 cm. or less in diameter, might suck constantly because in this area the muscles are scanty and the interspaces wide. A larger wound located posteriorly, in the heavy muscles of the back, might be less likely to suck.

Other considerations also determined whether or not a wound sucked. If the missile traversed the chest at such an angle that the external wound of entry was at a considerable distance from the point of its entrance into the pleural cavity, the movement of the intervening muscles of the chest wall might prevent the wound from sucking at one moment and permit it to suck at another. If the wound involved the muscles of the pectoral girdle, movement of the upper extremity on the injured side might so realine the openings in the skin and pleura that sucking occurred constantly.

Casualties with chest injuries were usually transported supine or in the sitting or semisitting position, but not many were wounded in these positions. Change of position after wounding therefore influenced the blowing characteristics of the wound.

Pathologic Physiology

Studies by Graham (*1*) (pp. 285–319 of reference cited) with Bell in World War I showed that a wound that exposes the lung and pleural cavity is not necessarily fatal. It can be tolerated if the amount of air entering the wound from the exterior is not greater than the difference between the tidal air and the original vital capacity. In the absence of treatment, the outcome is determined by the size of the wound and the original vital capacity.

The lung on the injured side does not collapse to the point of nonfunction when it is exposed to atmospheric pressure after wounding, even when the pleural cavity is free of adhesions (*2*). Furthermore, the pressures exerted on the exposed lung during the respiratory cycle are not always atmospheric.

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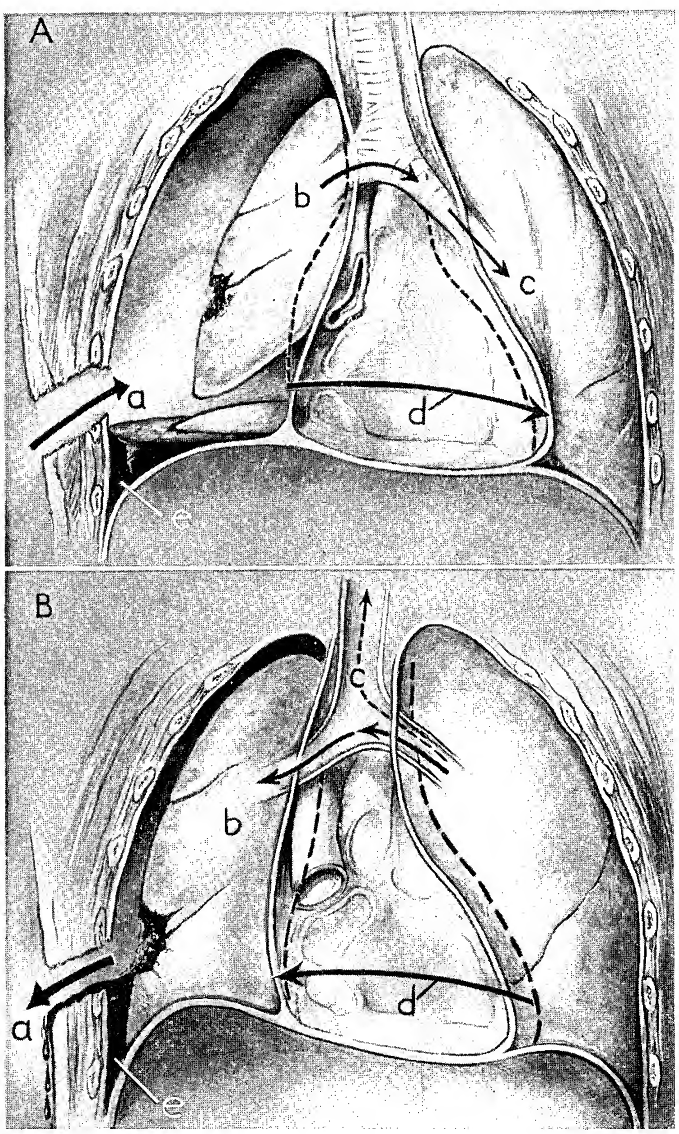

FIGURE 2.—Schematic showing of pathologic physiology of sucking chest wound. A. Entrance of air into chest on inspiration through wound in chest wall (a), the amount of air being directly proportional to the size of the opening as compared with the surface area of the open glottis. Collapse of lung on affected side (b), with passage of air out of affected bronchus. Entrance into bronchus of some air from collapsed lung (c), with passage to intact lung. Shift of mediastinum toward uninvolved side (d), hemothorax (e). B. Escape of air on expiration through sucking wound of chest wall (a). Expansion of collapsed lung (b). Passage of air from uninvolved side to lung on involved side, thence out trachea (c), producing the so-called pendular breathing. Shift of mediastinum to involved side (d). Hemothorax (e).

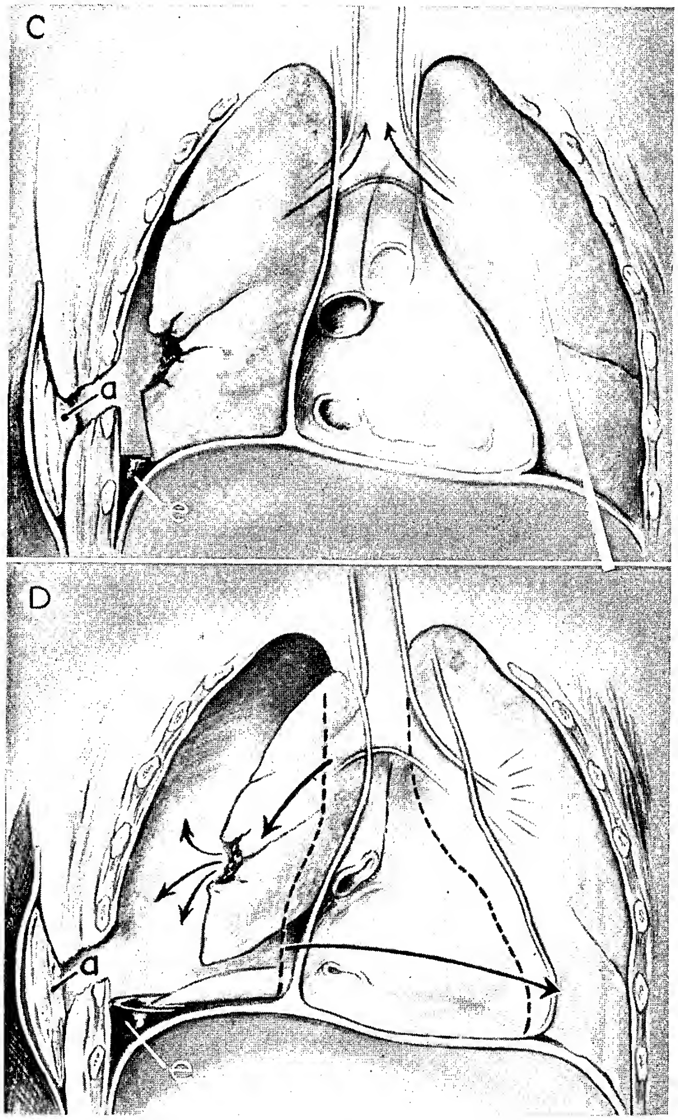

FIGURE 2.—Continued. C. Packing of sucking wound (a), after which respiration becomes more normal. Hemothorax (e). D. Development of tension pneumothorax because air cannot escape from tear in lung (a), after wound is adequately packed. If it develops, it must be treated by closed (catheter) drainage of cavity. Hemothorax (e).

The thorax is a flexible container, which moves during the respiratory cycle, and there may even be negative pressure in the exposed side during inspiration. The response to negative intrapleural pressure occasioned by enlargement of the chest on inspiration is a rush of air through the glottis. If the size of the traumatic opening is less than the size of the glottis, a sufficient amount of air enters through the glottis to answer the tidal air requirements and for functional necessities, and there is no danger of asphyxiation. When, however, the size of the wound approaches or exceeds the size of the glottis, the amount of air which enters the chest through the open wound during each inspiration is large enough to interfere with the tidal air requirement intake, and asphyxiation is a real danger.

Another factor must also be taken into consideration in the pathologic physiology of chest wounds, interference with the function of the contralateral side. In the healthy person, the mediastinum is not held down by adhesions or stiffened by previous inflammatory disease. It is therefore capable of transmitting pressure, and as a result, the intrathoracic pressure is likely to be almost identical in both cavities. In other words, the decrease in vital capacity caused by an open wound of the chest is bilateral in the normal person, whereas a casualty with a stiffened mediastinum can sometimes tolerate even very large wounds.

When the amount of air entering an open chest wound during each inspiration is large enough to interfere with the tidal air requirement intake, some degree of asphyxia is inevitable. A vicious circle then ensues:

1. There is an initial and increasing reduction in the vital capacity.

2. The mediastinum shifts with each inspiration and expiration, since it is no longer opposed by the lung on the injured side.

3. The mediastinal shift (flutter) increases in rapidity as the reduction in vital capacity increases.

4. The mediastinal shift has a direct and deleterious effect on the right heart, for anatomic reasons. The base of the heart is fixed, but the apex is relatively free. The apex therefore is capable of movement and is relatively unaffected by mediastinal flutter. The base is incapable of movement, and kinking of the large vessels that enter the right side of the heart is the next consequence of this phenomenon.

5. Pendulum respiration ensues and causes a further decrease in the vital capacity. On each expiration, air from the contralateral lung, with its predominant carbon dioxide content, is only partly exhaled. The residual amount enters the main and secondary bronchi on the injured side. On the next inspiration, the air taken into the uninjured lung is thus composed of both atmospheric air from the trachea and air from the injured lung, with a high carbon dioxide content.

Immediate Management

Casualties with large sucking wounds were usually in shock and non-transportable. All casualties with actual or potential sucking wounds were always in jeopardy, whether or not the wound was blowing at the particular moment of examination.

Surgical closure was necessary to bring about permanent restoration of normal cardiorespiratory physiology and to prevent intrapleural infection. This did not mean, however, that immediate surgical closure was necessary.

Early in the war, in obedience to the dictum that all sucking wounds should be closed promptly, attempts were often made to close these wounds hastily by suture as soon as the casualty reached the most forward medical installation. U.S. Army medical officers promptly learned, just as British medical officers had learned (vol. I), that this was a disastrous policy unless ample facilities were at hand for debridement and careful surgical closure. These facilities were not available ahead of a field hospital. When closure was undertaken without careful preliminary debridement, one or all of several complications might occur, including tension pneumothorax; extensive subcutaneous emphysema; or infection of the wound, with disruption, which produced a recurrence of the original sucking wound, with the difference that it was now surrounded by tissues that were infected and no longer suitable for approximation. The incidence of empyema was high in wounds that broke down after repair. It reached 50 percent in some series.

That treatment was a matter of extreme urgency was not open to debate. It was also quite simple. As already described (vol. I), medical aidmen were originally instructed to cover sucking wounds with an occlusive dressing (fig. 2C). Later, all chest wounds were treated in this way, on the ground that a wound that did not suck at one time or in one position might suck in another. On the battlefield, any type of dressing that was available could be used, even a piece of clothing. As soon as the casualty was brought to the battalion aid station, the temporary dressing was replaced by a larger dressing, preferably at least twice as large as the wound. It was thickly impregnated with petrolatum and was covered with a still larger gauze dressing held firmly in place with strips of adhesive. If the wound was very large, coarse sutures were placed through the skin and tied over the dressings.

This sort of dressing closed the chest efficiently for 5 or 6 hours, or longer. During this period, the patient was transported to a clearing station in which it was determined, by triage, whether he should be transferred to the adjacent field hospital for emergency surgery or could safely be transported to an evacuation hospital farther to the rear, though it was frequently necessary first to change the dressing. When a petrolatum-impregnated gauze dressing had become caked with blood, it had stiffened and was no longer pliable enough to act as a one-way valve. A needle with a flutter valve attachment was usually placed in the second interspace parasternally to provide for the escape of air and prevent tension pneumothorax (fig. 2D).

As the war progressed, emergency management of sucking wounds became so satisfactory that their potential seriousness was considerably minimized.

Surgical Closure

Small wounds.—Small sucking wounds, 2 cm. or less in diameter, although they were likely to blow continuously if they were located in portions of the thoracic cage where muscle was scanty, could usually be closed without difficulty. Lacerated skin and muscle were trimmed away, and accessible rib fragments were removed. Blood and clots were aspirated from the pleural cavity whenever they were present. In the absence of other indications, however, the wound was not enlarged into a formal thoracotomy for exploration or for removal of small metallic foreign bodies.

The pleural defect was usually closed by a few sutures in the intercostal muscle or, occasionally, by a small muscle plug in lieu of a pedicled graft. The more superficial muscles and the subcutaneous tissues were closed in layers, with sutures of fine interrupted silk. The skin was left open, to be closed at the base.

Intercostal water-seal drainage of the pleural cavity was frequently instituted, even in small wounds, both because the lung had often been injured and because air leakage was a possibility.

Large wounds.—Sucking wounds associated with large defects in the thoracic wall and with multiple rib fractures were usually grossly contaminated. Thorough excision of devitalized tissue was therefore necessary, together with excision of all loose rib fragments and of 3 to 6 cm. of the damaged costal ends. Excision was thorough, but as much periosteum and intercostal muscle and fascia was preserved as seemed safe. When a debridement had been carried out according to these principles, a traumatic thoracotomy had often been accomplished, through which intrapleural exploration could be conducted. Foreign bodies were removed if they were readily accessible. The lung was sutured if there was leakage of air or oozing of any consequence from the parenchyma. Otherwise, no lung surgery was done (p. 17). The pleural cavity was thoroughly cleansed.

The adequate exposure necessary for the debridement of large sucking wounds often made for difficulties in closure, particularly if the wound was in the anterior chest, where the muscle layer was scanty and the interspaces wider. Suture under tension had to be avoided. It was always undesirable, and it was particularly undesirable in contaminated areas. Even when the wound was located basally, the diaphragm was never used to close the pleural defect if other tissues could be utilized.

Closure of the deepest layer of the wound could often be effected by using the intercostal structures, periosteum, and deep fascia. If large segments of ribs had been removed, these tissues were relaxed and could be manipulated more readily. Relaxing incisions in the long axis of the intercostal bundles were helpful.

When necessary, the first muscle layer could be reinforced with pedicle flaps or muscles (vol. I), or the inferior surfaces of the deep muscles could be approximated to the first layer of the closure by interrupted sutures. When muscle tissue had been lost, subcutaneous dissection of the muscle sometimes simplified closure, or relaxing incisions might be employed at some distance from the defect. The subcutaneous tissues were usually closed, but skin closure was deferred. The dressings were applied with a moderate amount of pressure.

Tension pneumothorax was always a risk after a sucking wound had been closed. Some surgeons considered careful postoperative observation the only precaution necessary. Others preferred to use a safety valve in the form of a catheter with a flutter valve or a large-bore needle in the second anterior interspace.

Since the empyema rate was greater in sucking wounds associated with large defects of the thoracic wall, posterolateral closed intercostal drainage was sometimes employed. A second intercostal tube in one of the upper anterior intercostal spaces was useful in encouraging prompt reexpansion of the upper lobe. If empyema occurred, it was then limited to the base of the lung. If penicillin or a sulfonamide had been instilled into the chest and the posterior tube had been temporarily clamped off, the anterior tube could be relied upon to facilitate prompt expansion of the lung.

FRACTURES OF THE RIBS AND ADJACENT STRUCTURES

Simple Fractures

Simple fractures of the ribs were not common in combat-incurred injuries. When they were encountered in combat zones, they were usually the result of traffic or other civilian-type accidents. Relief of pain was secured by intercostal nerve block. Strapping was not practiced.

Solid, painless healing of simple rib fractures required about 6 weeks. If several ribs were fractured, another 2 or 3 weeks had to elapse before the patient could resume his full activities.

Simple fractures represented no threat to life, but they accounted for a considerable loss of manpower because of the time required for total convalescence.

Costochondral separations were remarkably infrequent. They were managed, like simple fractures, by intercostal nerve block. Recovery was usually prompt, but even if pain at the costochondral joint was persistent, joint resection was never practiced.

Simple fractures of the clavicle were managed by standard measures. Wiring was unnecessarily radical; it enhanced the chances of infection and could give rise to suppuration, which often was prolonged. Such heroic surgery was occasionally encountered early in the war, but it was never performed by physicians aware of the essential function of the clavicle and of its excellent natural capacity for recovery from trauma.

Simple fractures of the scapula were also infrequent in war wounds. They required only immobilization of the shoulder by a sling.

Acromioclavicular and sternoclavicular injuries as well as fractures of the glenoid fossa required special orthopedic care. Since they were not managed primarily by thoracic surgeons, they are discussed in the volumes on orthopedic surgery in this series.

Compound Fractures of the Ribs

About 75 percent of all combat-incurred penetrating and perforating wounds of the chest were associated with compound fractures of one or, more often, of several ribs. The scapula and clavicle were often similarly injured, and comminution of the bony structures might be extreme.

Pathologic process.—Occasionally, a tangential injury to the chest resulted in the fracture of one or more ribs in such a manner that the sharp edges of the fractured ribs penetrated the pleura even though the missile itself did not. Bone fragments from fractured ribs, because of their irregular, jagged edges and the respiratory movements of the chest, sometimes caused long, ragged pulmonary lacerations and other damage more serious than that caused by the original missiles. Even if this did not happen, penetration of the intact pleura by bone fragments could cause a pneumothorax, and continued trauma to the lungs by embedded bone fragments resulted, in a few cases, in both empyema and lung abscess. Both infection and sequestration were, however, remarkably infrequent, because of the almost universal practice of adequate debridement in forward hospitals.

Flail chest.—Flail chest, with paradoxical respiration, resulted from multiple fractures of several ribs. It was not often seen, but it was extremely serious because of the consequent reduction in vital capacity (fig. 3). The more the chest wall was sucked in toward the contralateral side during inspiration and the less it returned to the normal position on expiration, the greater was the decrease in vital capacity and the more the patient compensated by breathing faster.

Immediate management.—The immediate treatment of fractured ribs (fig. 4) was the relief of pain by intercostal nerve block, which usually lasted for 24 hours or more. When the casualty was able to breathe deeply, cough, and raise sputum, he became transportable, if associated wounds did not require forward surgery, and definitive treatment could be deferred until he reached an evacuation hospital.

Adhesive strapping was practically never used. It was often unsuccessful in accomplishing immobilization and relieving pain, and the adhesive often caused additional discomfort. Strapping was also unphysiologic. Many patients with fractures of the ribs showed varying degrees of wet lung with increased bronchial secretions and intrapulmonary bleeding. Raising the fluid would have been difficult or impossible because of pulmonary compression and the restriction of expansion of the chest caused by strapping.

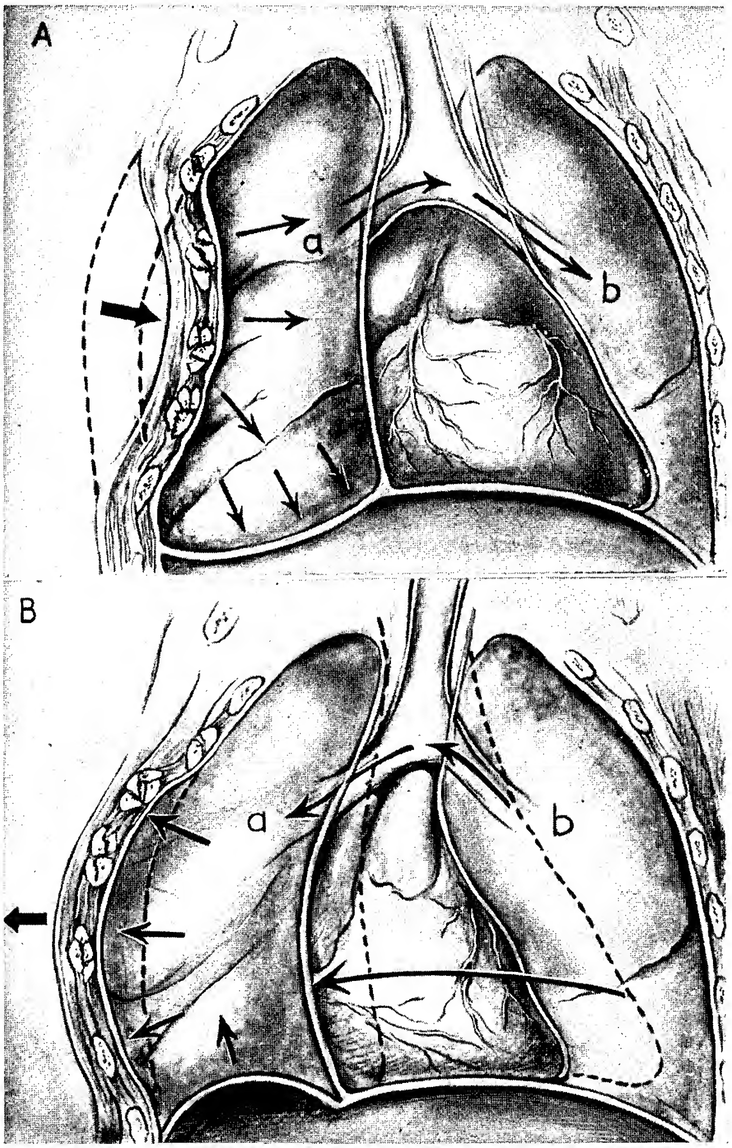

FIGURE 3.—Schematic showing of pathologic physiology of flail chest. A. Inspiratory phase. Chest wall collapses inward (a), forcing air out of bronchus of involved lung into trachea and bronchus to uninvolved lung and causing shift of mediastinum to uninvolved side (b). B. Expiratory phase. Chest wall balloons outward (a) so that air expelled from lung on uninvolved side (b) enters lung on involved side and mediastinum shifts toward involved side (a). This is a very inefficient form of respiration, and the patient will die of hypoxia and exhaustion if it occurs in an extreme phase and is not relieved.

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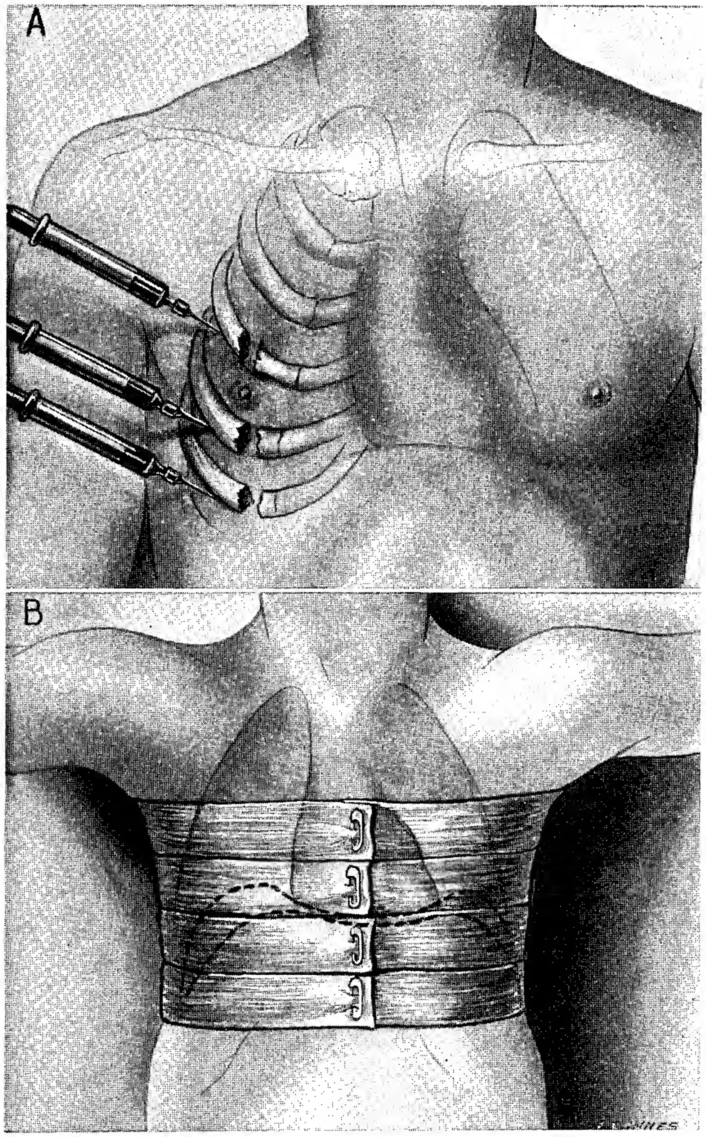

FIGURE 4.—Management of flail chest. A. Intercostal nerve block, to block painful impulses on affected side and thus cut down paradoxical respirations and allow for deeper breathing and more effective cough. (For further details of technique, see fig. 68, p. 220.) B. Application of circumferential elastic binder, to prevent chest wall from ballooning out on inspiration and to allow diaphragm to function more effectively.

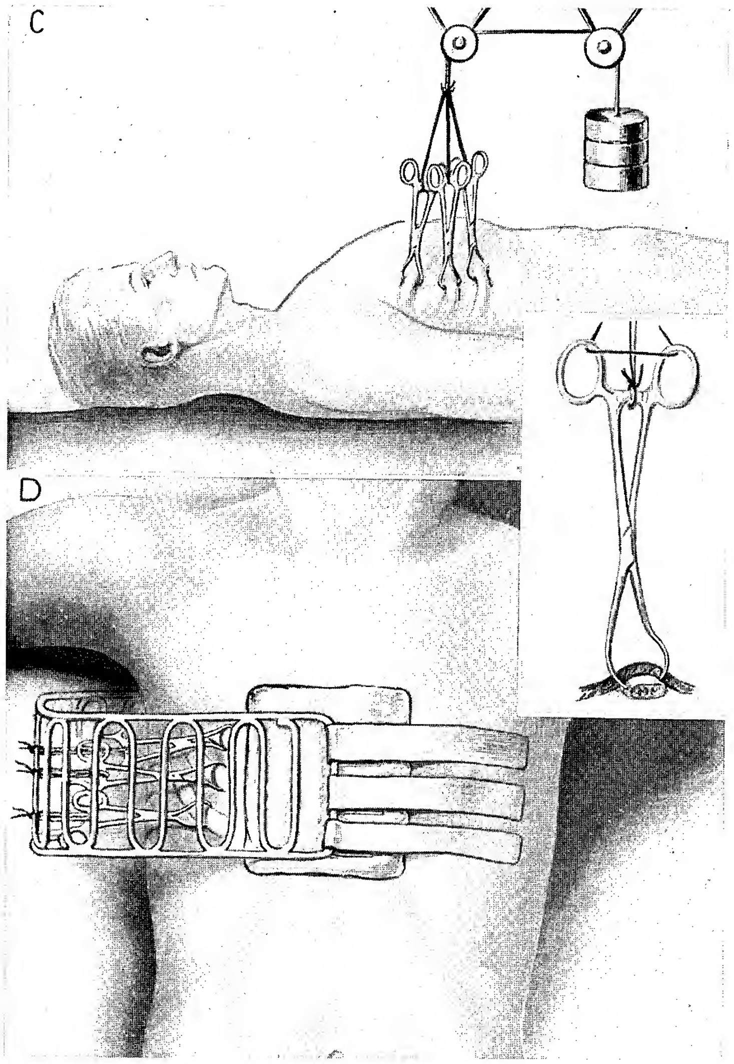

FIGURE 4.—Continued. C. Overhead traction. Whether the injury is a fracture of the sternum, the cartilages, or the ribs, the paradoxically moving portion of the chest may be stabilized by the use of large towel clips fixed into the ribs or other damaged structures or by wire passed underneath them. Stabilization could usually be accomplished successfully by the use of two pulleys and weights, of not more than 5 pounds. D. Wire splint, fixed on either side of flail portion of chest, supports towel clips or wires attached to the fractured ribs by means of rubberbands.

In civilian practice, a patient with flail chest would be ideally treated in a respirator. This was, of course, completely impractical in military surgery. Nerve block often resulted in a considerable improvement in symptoms and a considerable reduction in the paradoxical movement of the chest wall. If it was not successful, adhesive strapping, undesirable as it was, sometimes had to be employed, or an elastic binder was used. Positioning with sandbags was occasionally useful, but traction was seldom employed. If simpler measures were not succeessful, operation had to be resorted to. Costal fixation was secured by placing stainless steel wire or heavy silk through the ends of the shattered ribs. Tracheotomy was sometimes necessary also.

Surgical management.—The surgical management of fractures of the ribs required careful individualization of patients. In most instances, debridement could be limited to the soft tissues. If the wound was tangential, there might be extensive comminution of from three to five ribs without penetration of the pleura. Often the greater portion of the damage was subscapular. In a few cases, roentgenograms showed what looked like a picket fence of bony spicules along the parietal pleura.

Whenever debridement included the removal of irregular, subpleural rib fragments, the pleural cavity was necessarily entered, and the surgeon had, in effect, performed a thoracotomy. He had to have sound reasons for extending the wound and increasing the magnitude of the operation. The mere presence of bone fragments within the pulmonary parenchyma was not an indication unless they seemed responsible for continued bleeding or for an air leak.

One exception to this generalization was the presence of fragments partly within the pulmonary parenchyma and partly within the pleural space. Fragments in this location could produce a good deal of trauma when the lung reexpanded and they came into contact with the chest wall. Both air leaks and infections were possible sequelae. A number of cases were observed in which the lung, the pleural cavity, and the chest wall were all involved in the infection that followed debridement carried down only to the muscles, the bone fragments being left in situ.

WOUNDS OF THE LUNGS

General Considerations

Lacerations of the pulmonary parenchyma were encountered in practically all perforating chest wounds. They varied from small puncture wounds to very extensive lacerations.

When surgeons, early in the war, first encountered badly contused, lacerated, boggy, hemorrhagic lungs, they found it hard to refrain from immediate lobectomy. In fact, this operation would probably have been done rather often if the casualties had not been in such poor general condition or had not had associated major wounds. For these reasons, pulmonary surgery

was, of necessity, limited to simple suture. The sutures, also of necessity, were superficial, since the friable, hemorrhagic tissues were incapable of holding deep sutures. The practice was to perform one-layer closure, with interrupted sutures of fine, nonabsorbable material on an atraumatic needle. It proved surprisingly easy to secure an airtight closure in this manner, one reason being that the tendency to leakage was diminished by the fact that the damaged lung was somewhat slow to aerate completely. Roentgenograms examined 2 or 3 weeks after surgery showed remarkable clearing of the lung fields, and clearing was usually complete in 6 to 8 weeks.

One reason for these good results can be explained in the form of an analogy: Engineers found that the best protection for wiring in airplanes was simply to fasten the wires loosely along the side of the plane. Missiles that passed through wires thus placed seldom damaged all of them, whereas if the wiring had been placed in a conduit, a single bullet that struck the container could divide all of the wires in it. The same phenomenon was observed in the lung. The blood vessels are surrounded by an elastic medium that permits them to be easily displaced in any direction when a foreign body strikes them. As a result of this physiologic capability, damage to the lungs was frequently more limited than it might otherwise have been.

The real explanation of the tremendous recuperative power of the lung is its dual blood supply, through the pulmonary and bronchial arterial systems. The blood supply, being in the form of a tree, was irreparably damaged only when the trunk was severed. Since all the major blood vessels branch out radially from the hilus, they had to be damaged near the point of origin to cause lethal damage to the pulmonary parenchyma.[1] Undoubtedly there were many such injuries in World War II, but the casualties who sustained them did not live long enough to reach field hospitals.

Management in Forward Hospitals

As the war progressed, the policy of leaving small lacerations of the lung unsutured became general. No untoward effects were noted. Untreated lungs were found to expand as well, and about as rapidly, as lungs which had been sutured. These observations bore out the theory that the surrounding airless lung, when it was infiltrated by blood, prevented postoperative parenchymal pleural fistulas.

Eventually it became the custom to suture lacerations of lung tissue only on the following indications:

1. Obvious parenchymal pleural fistulas.
2. Large lacerations, chiefly to reduce the amount of postoperative drainage.

[1] Wartime observations are borne out by a series of experiments on the pathologic effects of foreign bodies in the pulmonary artery reported in 1959 (*3*). These studies showed that the lung can recuperate when a branch of the artery or the lobar pulmonary artery is completely blocked. Only when the main artery is blocked will the pathologic changes be irreversible. Severe pathologic changes result, however, when the bronchial artery and the pulmonary artery to the involved lobe are blocked.

3. Lacerations bleeding into the pleural cavity.
4. Lacerations bleeding into the tracheobronchial tree.

It was logical to repair pulmonary lacerations that were oozing actively or that presented serious air leaks. It was particularly important to suture lacerations that were bleeding into the tracheobronchial tree. In these circumstances, even with repeated endotracheal suction, it would have been difficult to keep the airway free of blood.

If the chest was to be drained, closure of a small air leak was not considered important. Air leaks were identified by filling the hemithorax with physiologic salt solution under pressure of 10 to 15 mm. H_2O; it was necessary that the lung be completely covered with the solution.

There was no indication for pulmonary repair in the contusion type of injury, since it caused either scattered areas of hemorrhage in both lungs, as in blast injuries, or massive bleeding that involved all the lobes. This therapeutic point of view is in interesting contrast to the World War I concept that all hemorrhagic infiltrations ("splenizations") had to be resected if a fatal issue were to be prevented (*4*).

Occasional small peripheral wedge resections were performed for localized areas of necrosis around foreign bodies. Otherwise, there were few valid indications for resection in forward hospitals. They were limited to:

1. Irreparable damage to a major bronchus.
2. Partial traumatic amputation of a portion of a lobe in which the bronchi had been transected and little or no blood supply remained.
3. Damage to major pulmonary vessels of such a character as to require complete ligation. Very few patients in this category lived long enough to reach a forward hospital.

The records of the 2d Auxiliary Surgical Group, covering 2,267 thoracic and thoracoabdominal wounds, show only a single lobectomy in a forward hospital, on a patient who died in the course of the operation. Pneumonectomy was not attempted in any instance.

Management in Base Hospitals

Even in base hospitals, indications for pulmonary resection seldom arose. An occasional peripheral wedge resection was performed, as in forward hospitals, to remove a localized area of necrosis around a foreign body or on the indication of a small peripheral posttraumatic abscess or multiple bronchopleural fistulas. The tissue to be excised was held between clamps. After hemostasis had been secured, the raw edges of the lung were sutured together, and the edges of the pleura were inverted with two rows of interrupted sutures of fine silk. Air leakage did not occur with this type of suture.

The experience of the 2d Auxiliary Surgical Group shows how infrequent was the need in World War II for the radical excision of lung tissue. Maj. Thomas H. Burford, MC, and Maj. (later Lt. Col.) Paul C. Samson, MC, found it necessary to perform only one lobectomy and only two total pneumonectomies

in the base hospitals in which they worked. In retrospect, they questioned the wisdom of all three operations:

The lobectomy was performed for a massive liquefied hematoma of the upper lobe, which had shown no evidence of regression over a 4-week period. The patient died on the operating table. In this case, simple external drainage would probably have been wiser.

The first pneumonectomy was performed on the indication of a chronic fistulous tract resulting from a penetrating shell-fragment wound. The tract was more than 1 cm. in diameter and extended through both upper and lower lobes at the hilus. Surgical obliteration was impractical. The patient survived the pneumonectomy but eventually died from empyema and purulent pericarditis.

The second pneumonectomy, in which death occurred from the same causes, was performed on the indication of multiple recurrent fistulas, a collapsed lung, and an infected hemothorax. The original injury was a perforating wound from a rifle bullet. Pathologic examination of the excised specimen showed multiple areas in which alveoli were ruptured, and widespread vascular damage was indicated by thrombosis of numerous small vessels. In this case, it would probably have been wiser merely to drain the empyema and accept the collapse of the injured lung as permanent.

The results in these cases show that the mortality for pulmonary resection performed for thoracic injuries or their sequelae is so high that operations of this sort are seldom if ever indicated. They should be undertaken only on clear-cut indications and only after the most careful consideration.

In the Mediterranean theater, an increasingly conservative attitude toward lobectomy and pneumonectomy was gradually crystallized as experience in the management of combat-incurred casualties increased. In the last year of the war, in treating a series of 338 chest injuries at the 21st General Hospital, Maj. Lyman A. Brewer III, MC, found no indication for lobectomy in any of the patients. In one case, it was thought that lobectomy might be necessary later, but the decision was deferred until the lung had had a chance for maximum recovery and the patient could be studied more deliberately in the Zone of Interior.

WOUNDS OF THE MEDIASTINAL STRUCTURES

General Considerations

Wounds of the mediastinal structures were uncommon in forward hospitals, chiefly because injuries to adjacent vital structures were usually lethal. Mediastinal wounds included injuries of the larger hilar blood vessels, which were usually promptly fatal; injuries of the intrathoracic trachea and major bronchi; and injuries of the esophagus. Diagnosis, which was difficult and confusing, was based upon the following considerations:

1. The projected course of the missile was the most useful index of possible damage.

2. Signs of continuing intrapleural hemorrhage were frequently, but not necessarily, present when a large blood vessel had been injured.

3. Injuries to the trachea and major bronchi caused a rapid accumulation of air in the pleural cavity, freqently under increased pressure. Whenever leakage of air continued, it could be assumed that a bronchus or branch bronchus had been injured.

4. Mediastinal emphysema of varying degrees was frequently present, as the result of wounds of the hilar bronchi, trachea, or subglottic larynx, though in the experience of the 2d Auxiliary Surgical Group, the air was never under sufficient pressure to obstruct the venous return to the heart and give rise to symptoms. It was the opinion of these surgeons that most of the symptoms ascribed in the literature to mediastinal emphysema were more probably caused by an unrecognized associated pressure pneumothorax. The ease with which, in many cases, air in the mediastinum dissected into the pleural cavity was explained by the absence, in most World War II soldiers, of old pleural disease and subsequent pleural thickening and adhesions. The most frequent clinical evidence of mediastinal emphysema was a precordial crunch or click synchronous with the heartbeat.

Management

Correction of the pressure pneumothorax usually stabilized the patient sufficiently to permit whatever surgery was necessary. Only occasionally were suprasternal incisions into the deep fascial planes necessary as an emergency procedure to relieve emphysema.

Exploration in injuries of the mediastinum was usually carried out for one of two reasons, suspected injury to the esophagus or continued bleeding from large vessels or from the heart. The mere demonstration of shell fragments within the mediastinum was not considered a sufficient indication for surgery in the absence of one or the other of these indications.

Enlargement of the mediastinum by extravasation of blood, as demonstrated by roentgenograms, was not an indication for exploration unless there were also signs of obstruction of the superior vena cava, as shown by progressive swelling of the cervical veins or unless progressive enlargement of the mediastinal shadow suggested continued hemorrhage. Considerable enlargement of the superior mediastinum sometimes accompanied wounds of the neck as the result of dissection into it of blood from a cervical vessel. It was the rule to investigate wounds in the neck thoroughly, before proceeding with such extensive operations as removal of a part of the clavicle and the sternum, in the hope that, even if the missile was in the superior mediastinum, the source of the hemorrhage might be reached from above or might become accessible by exposure at the base of the neck. When a missile in this region could not be readily removed, the area could be drained through the cervical wound.

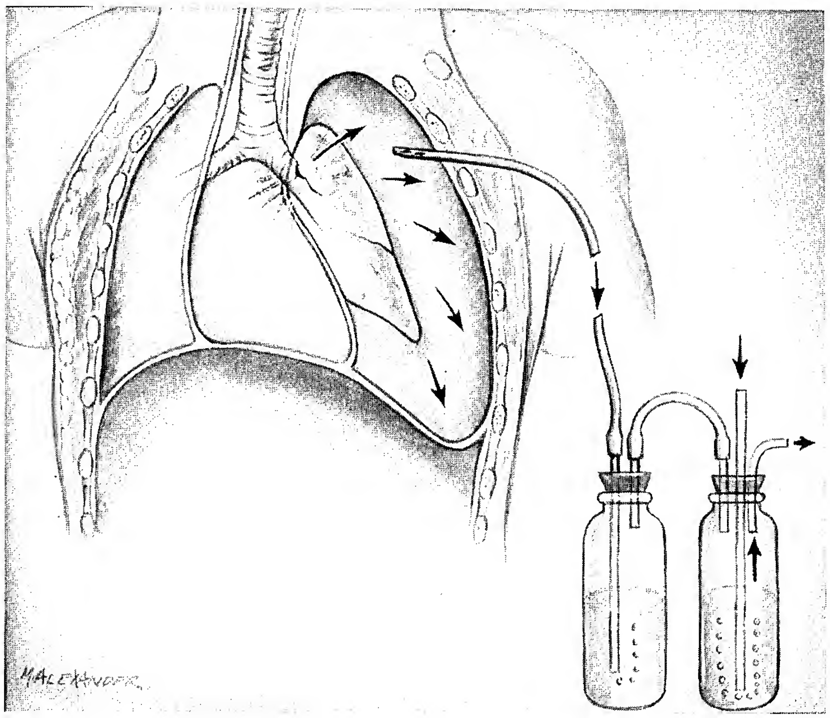

FIGURE 5.—Schematic showing of results of laceration of main bronchus. This injury will always produce a pneumothorax with leakage of large amounts of air even under closed drainage with strong suction. Thoracotomy is indicated.

As a matter of convenience, wounds of the trachea and bronchi and of the esophagus are discussed separately.

WOUNDS OF THE TRACHEA AND BRONCHI

General Considerations

Injuries of the intrathoracic trachea and main bronchi were extremely uncommon in forward hospitals, chiefly because, if they were of consequence, death promptly occurred on the battlefield. The few patients who survived to reach the hospital—there were only 4 in the 2,267 thoracic and thoracoabdominal injuries encountered by the thoracic surgical teams of the 2d Auxiliary Surgical Group—were in severe cardiorespiratory imbalance. None of them presented a sizable intrathoracic laceration of the trachea.

Unless casualties with this kind of injury had also sustained a traumatic thoracotomy, wounds of major bronchi were characterized by a rapid, complete collapse of the affected lung, associated with an extreme degree of pressure pneumothorax (fig. 5). Subcutaneous emphysema might be extreme, extend-

ing from the scalp down to, and into, the testicles. When the trachea was the site of a major wound, both lungs were collapsed and the patient usually died very quickly.

These findings, combined with the location of the missile, pointed to the diagnosis, particularly in injuries of the trachea. The only possible source of confusion was a sucking wound at the apex of the lung anteriorly, which might be mistaken for a perforation of the trachea.

Management

In wounds of the trachea and bronchi, immediate, adequate decompression was imperative. It was best accomplished by the introduction into the second interspace anteriorly of a large catheter, which was connected with a water trap. Large amounts of blood were frequently present in the pleura, and unless thoracentesis was also carried out promptly, the patient could drown from the sudden entrance of this blood into the tracheobronchial tree. The diagnosis was established if the lung did not reexpand completely when these procedures were instituted; the bubbles of air expelled during quiet expiration could be observed in the water-seal drainage.

If bleeding was not severe, it was best to restablish the cardiorespiratory balance before operation was undertaken. If bleeding was continuous, operation had to be performed promptly. Even if the diagnosis was only suspected, thoracotomy was warranted, since both the bronchi and the trachea lend themselves quite well to suture.

A high posterolateral approach, preferably on the right side, provided the best exposure for wounds of the trachea. Repair was accomplished by simple closure with interrupted sutures of fine silk. If there was loss of substance in the tracheal wall, mediastinal tissue, pleural tissue, or a long-pedicled flap from the latissimus dorsi could be used to aid in the repair. Occasionally, in high tracheal wounds, repair was accomplished through an anterior approach, with division of the clavicle.

The diagnosis, or even the suspicion, of injury to a major bronchus was an indication for exploration. The mere existence of damage to a bronchus was not, however, an indication for lobectomy, though if the vein or artery to a lobe of a lung was lacerated, resection might conceivably be necessary. Not many such injuries were seen because they led to rapid exsanguination, and the casualties did not usually survive long enough to reach even forward hospitals. In contrast to the general experience, Maj. Robert H. Wylie, MC, had two recoveries after operation for injuries of major bronchi.

In one case in which serious bleeding from an upper lobe bronchus made anesthesia hazardous, Maj. (later Lt. Col.) Lawrence M. Shefts, MC, packed the main stem bronchus under endoscopic vision. It was then possible to occlude the blood supply temporarily and proceed with the repair of the damaged bronchus. The procedure in this case was lifesaving.

Case History

Col. Edward D. Churchill, MC, Consultant in Surgery to the Surgeon, Mediterranean Theater of Operations, U.S. Army, early predicted that no patient with an injury to a left main stem bronchus would survive to be treated in a forward hospital, as the anatomy of the left hilar region made it inevitable that a missile could not pass through it without inflicting fatal damage. No such injuries were observed. Lt. Col. W. Paul Sanger, MC, observed two casualties with damage to the right main steam bronchus. Both survived to be hospitalized because of the unusual tactical situation: Both were wounded on the Anzio beachhead, in close proximity to the hospitals to which they were admitted. One of them died early in the postoperative period because of overwhelming pleuropulmonary sepsis. The history of the other follows.

Case 2.—This casualty was hospitalized within an hour after he had sustained a shell-fragment wound of the eighth posterior interspace on the right side, presumably while prone. He immediately became dyspneic and was unable to move the lower extremities. When he was admitted, he was in shock and was completely paralyzed below the eighth dorsal segment. Respiration was profuondly embarrassed, obviously because of a large wound, 5–6 cm. in diameter, in the eighth right interspace posteriorly, which was sucking air and draining blood. It was filled with bits of clothing and bone fragments. The sucking was controlled at once with petrolatum-impregnated gauze packs. Paravertebral block of the sixth to the tenth intercostal nerves greatly improved the respirations and permitted the patient to cough up large amounts of blood. The blood pressure was elevated to 86/52 mm. Hg by the infusion of 25 gm. of serum albumin. Aspiration of the chest produced 800 cc. of blood, which was immediately returned to the patient by autotransfusion. Insertion of an intercostal catheter relieved the developing pressure pneumothorax.

By 9 hours after injury, the patient had become fairly well stabilized. Then there was a sudden increase in the pneumothorax. Emergency surgery was performed, under endotracheal anesthesia. The wound in the region of the eighth right rib was excised, and a posterolateral thoracotomy incision was made in the eighth right interspace. A large, ragged, bullet-shaped shell fragment, 12 cm. long, was found penetrating the posterolateral wall of the right main stem bronchus, just distal to the bifurcation of the trachea. Air and blood were pouring freely from the wound. The azygos vein was lacerated; it was sutured, without complete occlusion. Then, with considerable difficulty, the defect in the bronchus was approximated with interrupted silk sutures; the closure was reinforced with muscle. When the closure was water-tested, there was no evidence of leakage.

A transverse laceration of the upper lobe of the right lung, between 12 and 14 cm. long, was closed with interrupted silk sutures. The lung was then reexpanded except for the portion of the upper lobe in the area of laceration. The incision was closed in anatomic layers.

The patient received 1,000 cc. of blood and 250 cc. of plasma during the operation and was in fair condition at the end.

The immediate postoperative course was stormy, not because of the chest wound but because of the distention and other complications that accompany cord transection. Suprapubic cystostomy was done on the seventh postoperative day, and a hip spica was applied, to facilitate evacuation.

The right lung remained expanded, but on the 12th day, the incision became infected in the area of the original wound. Empyema followed; such an experience shows the unwisdom of including the wounded area in the thoracotomy incision. Treatment consisted of the intramuscular injection of 25,000 units of penicillin every 3 hours for 10 days; no sulfonamides were given.

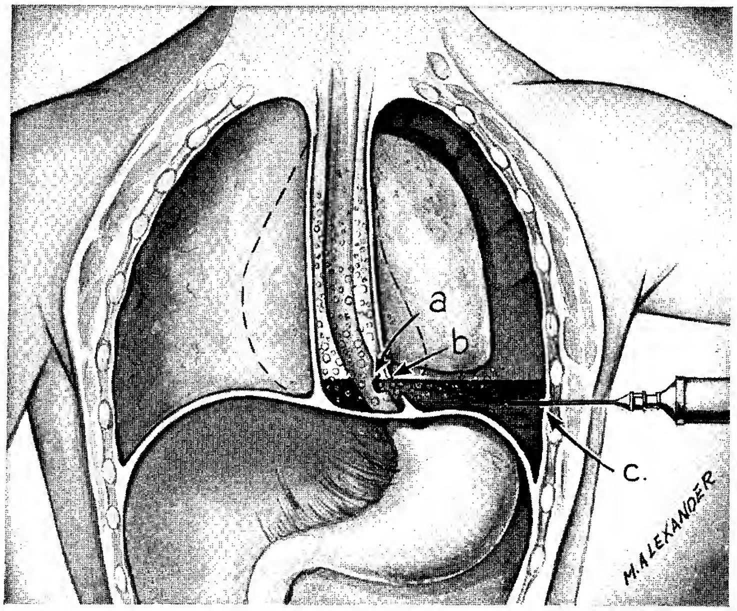

FIGURE 6.—Thoracic laceration of esophagus. Hydropneumothorax produced by fluid and air escaping from esophagus (a), and through rupture of mediastinal pleura (b). Aspiration of esophageal fluid from pleural cavity is diagnostic (c).

Reports from the base hospital a month after wounding stated that the empyema cavity was still from 200 to 300 cc. in volume. There was some return of sensation in the extremities. The last report, 4 months later, stated that progress was continuing to be good.

WOUNDS OF THE ESOPHAGUS

Incidence

Wounds of the thoracic esophagus were uncommon. In the 1,364 thoracic wounds and 903 thoracoabdominal wounds cared for by the surgeons of the 2d Auxiliary Surgical Group, there were records of only 6 cases. In one of these, the diagnosis was doubtful; the surgeon who removed the missile from the wall of the esophagus noted that he did not think that the lumen had been penetrated. The two other cases in which surgery was done ended fatally, and the three remaining cases were diagnosed only at autopsy. This surgical group, therefore, with its wide experience of thoracic injuries, had no record of certain recovery from a confirmed penetrating wound of the intrathoracic esophagus.

Diagnosis

Diagnosis of wounds of the esophagus (figs. 6 and 7) was difficult, but it was imperative that it be made because continued spillage in an unrecognized wound was likely to be followed by mediastinal infection (fig. 8), which was

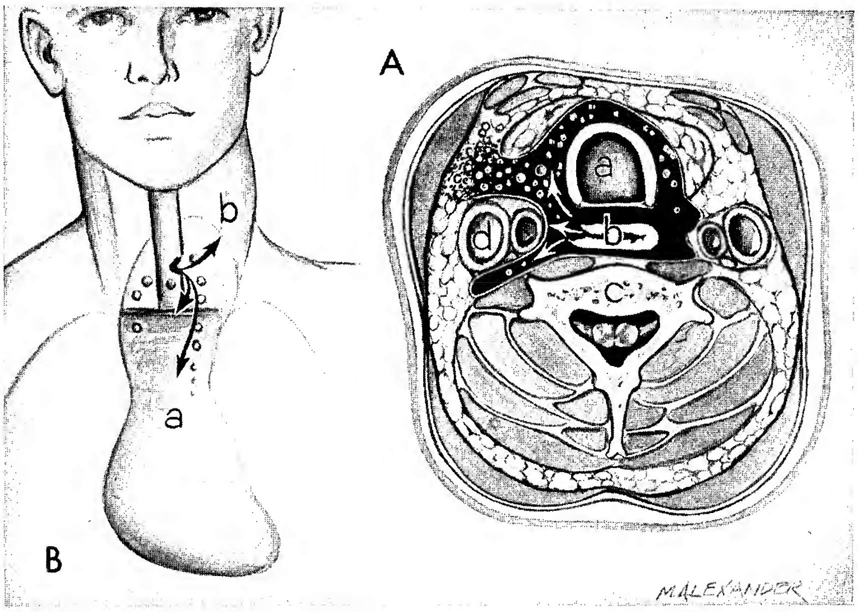

FIGURE 7.—Cervical laceration of esophagus. A. Air and fluid spread through deep cervical fascial planes: Trachea (a), esophagus (b), sixth cervical vertebra (c), and carotid sheath (d). B. Deep abscess formation, pointing to mediastinum (a) or, less often, externally (b).

often fatal, or massive fulminating empyema. The chief diagnostic difficulty was that neither symptoms nor signs were consistent and that suspicion was frequently not aroused until serious complications had ensued. Another difficulty was that many of the symptoms and signs present were related to wounds of associated structures, particularly large sucking wounds and massive hemothoraces, and tended to overshadow whatever clinical picture might be produced by lacerations of the esophagus.

Perhaps the most common symptom of esophageal injury was continued substernal discomfort, with acute substernal pain on swallowing. True dysphagia was not the rule. Severe pain in the back, radiating down into the lumbar region, was pathognomonic when it was present. Typically, it was not alleviated by large doses of morphine. The probable origin of the pain was the inflammatory reaction in the posterior mediastinum caused by leakage from the esophagus.

Mediastinal emphysema was often present and was sometimes associated with cervical emphysema. Equally often, it was absent, for the opening in the mediastinal pleura that usually was a part of such injuries permitted the escape of air into the pleura (fig. 6). The presence of a pneumothorax was not always helpful, for the missile which had penetrated the esophagus might very well have penetrated or perforated the lung also.

FIGURE 8.—Acute suppurative mediastinitis secondary to perforation of esophagus. Note widening of retrotracheal space and air in tissues.

Projection of the track of the missile was not helpful in many cases because a hemothorax or hemopneumothorax might obscure the path which the missile had taken in traversing the lung. If, however, one kept in mind the exact position of the esophagus in various parts of the thorax in relation to the location of the missile, as demonstrated by anteroposterior and lateral roentgenograms, it was often possible to make diagnostic assumptions. This help was not available when a missile of moderate size had passed completely through the mediastinum.

If an injury of the stomach could be ruled out, blood obtained on the passage of a Levin tube was an indication of possible esophageal injury. If roentgenograms showed a widening of the mediastinal shadow, a swallow or two of thin barium or Lipiodol was given and additional roentgenograms taken. Mediastinal widening was, however, a confusing finding, for it might also be caused by injuries at the base of the neck. The aspiration from the pleural cavity of gastric juice or of fluid containing food particles was pathognomonic of a gastrointestinal perforation. Food particles were identified by the naked eye. The presence of gastric juice was readily determined by the very acid

reaction of litmus paper to it. If the diaphragm was not injured, these findings were evidence of a perforation of the esophagus.

As a practical matter, the diagnosis of injury to the thoracic esophagus was chiefly made on suspicion, aroused by whichever of the signs, symptoms, and roentgenologic findings just listed might be present in the particular case. It almost always had to be confirmed by exploration, which was warranted even if the suspicion was based on nothing more concrete than knowledge of the course of the missile in a perforating wound or of its position in a penetrating wound. Any rent in the posterior mediastinum or any hematoma in this region found in the course of exploration of the chest on other indications was always investigated, with the possibility of injury to the esophagus in mind.

Management in Forward Hospitals

The extremely high mortality of wounds of the esophagus, as just noted, made it mandatory to perform an exploratory operation on the slightest suspicion that such an injury existed. The limited World War II experience, however, makes it impossible to make definitive statements about management.

If the patient's condition did not permit immediate operation, the best plan was to intubate the stomach, withhold all food by mouth, and keep the patient under penicillin protection.

When surgery was indicated, the esophagus, if the wound was in the upper third, was best exposed from the right side, by a posterolateral transpleural approach. If both wound and missile were on the left side, a left-sided approach was indicated.

The margins of the esophageal wound were excised back to healthy tissue. Then a two-layer closure was carried out, with the second layer of sutures in the musculature. Interrupted sutures of fine silk were used. The mediastinal pleura was left open. The pleural space was drained with two intercostal water-seal drains.

The single patient observed by the 2d Auxiliary Surgical Group on whom this total technique was used did not survive, because of other wounds, but for the 5 days he lived after operation, there was no clinical evidence of leakage from the esophagus or of pleural involvement. Post mortem examination, unfortunately, was not carried out.

Most surgeons of experience considered extrapleural posterior mediastinotomy both useless and harmful because it jeopardized the first objective of the operation, complete and permanent reestablishment of esophageal continuity. Once this was accomplished, drainage, in their opinion, would add little to the safety of the patient and might encourage breakdown of the wound. Posterior mediastinotomy was, in fact, an operation of limited usefulness in combat-incurred chest wounds.

Postoperative management.—Gastrostomy for nutritional purposes was not considered necessary in a forward hospital. If decompression was required,

a Levin tube was used, either passed into the stomach, or, as advocated by Sweet (*5*) in resections of the esophagus, passed down to the site of repair.

Management in Base Hospitals

While few patients with undiagnosed wounds of the esophagus were encountered in base hospitals, it was necessary to be on the alert for such injuries. Rapid development of a fulminating empyema and aspiration of a thin pleural exudate with a musty odor characteristic of gastric juice were almost pathognomonic of an esophagopleural fistula. If methylene blue taken by mouth appeared in the pleural space, the diagnosis was confirmed. The site of the injury was localized by fluoroscopy after the patient had been given a swallow of Lipiodol or thin barium solution. If a tracheoesophageal fistula was suspected, diagnosis was made by bronchoscopy.

Once the diagnosis was made, immediate rib resection was carried out, and a large rubber tube was inserted into the empyema cavity. For the first few days, the tube was connected to a water-seal bottle. Gastrostomy was performed at the same operation even if the wound in the esophagus was very small. In this sort of case, intubation was often tried, with nothing by mouth. Full doses of penicillin were given intramuscularly.

The patient was nursed in the sitting position, to reduce the tendency to regurgitation, which was present in practically every case. Gastric contraction to a degree incompatible with nutritional needs was common, and the associated pylorospasm, which was probably the result of vagal irritation resulting, in turn, from mediastinal involvement, made continuous regurgitation almost inevitable. Unless it could be controlled, healing of the esophagus was delayed. If regurgitation was troublesome after an otherwise satisfactory gastrostomy, jejunostomy was resorted to. In addition to preventing regurgitation, the jejunostomy served admirably as a feeding route. The gastrostomy stoma then served as a decompressive vent.

The criterion of satisfactory progress was closure of the esophageal fistula, reexpansion of the lung, and obliteration of the empyema cavity. If these results were not accomplished by this regimen, a direct surgical attack was made, consisting of thoracotomy, decortication, and closure of the esophageal opening.

Case Histories

The following case histories illustrate the difficulties and complications of wounds of the esophagus:

Case 3.—A paratrooper who was wounded in action on 15 September 1944 sustained a perforating bullet wound of the right chest. The wound of exit was to the left of the midline, just to the left of the xiphoid process. Debridement was carried out after resuscitation. There were no symptoms or signs to suggest a wound of the esophagus.

When the patient was received in a base hospital 5 days after wounding, he was critically ill. Investigation revealed a large total empyema on the right side, with a

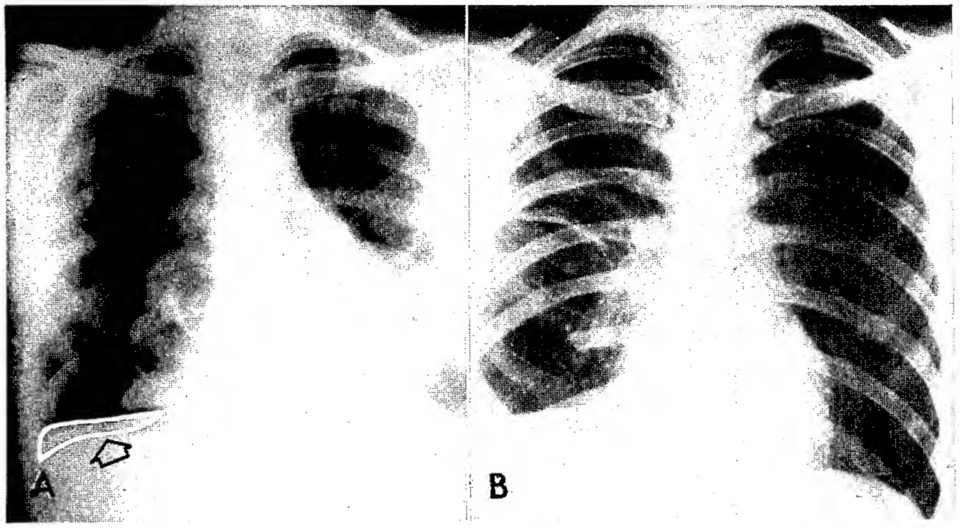

FIGURE 9.—Large esophagopleural fistula with total right pyopneumothorax. A. Posterolateral roentgenogram. Note barium at right base. B. Same, 6 weeks after thoracotomy with pulmonary decortication and repair of fistula. A complete cure resulted.

large esophagopleural fistula (fig. 9A). Forty-eight hours later, the empyema was drained under local analgesia by rib resection, and gastrostomy was performed.

The patient improved, but leakage of regurgitated material through the fistula remained profuse, and the lung showed no tendency toward reexpansion. Four weeks after wounding, thoracotomy was performed, with decortication and closure of the 2-cm. longitudinal defect of the esophagus just above the cardia. The esophagus had been pulled well to the right by the changes consequent to injury and to subsequent infection. Operation was performed without difficulty, and pulmonary expansion was immediate and complete. Closure was effected in two layers, by interrupted sutures of fine silk, with inversion of the knots. Fibrin foam was sutured over the site of the repair. The mediastinal pleura was closed, and the usual water-seal intercostal catheter drainage was instituted.

The immediate postoperative course was uneventful, but regurgitation was troublesome, and recurrence of a small basal empyema required secondary drainage by rib resection. Methylene blue given by mouth appeared in the pleural exudate at the end of 2 hours, and fluoroscopic examination after a swallow of Lipiodol showed a very small leak at the site of repair. After jejunostomy was performed, there was prompt relief of regurgitation as well as rapid obliteration of the basal empyema cavity (fig. 9B). When the patient left the hospital, his condition was excellent in all respects.

Case 4.—This patient received his initial surgery in a British mobile field hospital. A tommygun bullet had penetrated the neck at the base on the right side and traversed it obliquely, emerging at the posterior margin of the left sternocleidomastoid muscle. The right thyroid lobe was damaged, the right lateral wall of the trachea opened, and the esophagus almost completely transected.

At operation, a few hours after injury, the trachea was repaired and the esophagus was closed by end-to-end suture, presumably with catgut. The wound was closed with drainage, and gastrostomy was done.

At the end of 5 days, the neck began to swell, and on the seventh day, the anterior wound broke down and began to discharge both purulent exudate and esophageal secretions. When the patient reached the 21st General Hospital, he had a large esophageal fistula, with

considerable infection. Vomitus was aspirated into the lung when he vomited soon after admission, and a typical aspiration pneumonia further complicated the clinical picture. After a stormy period, the pneumonia cleared, and the cervical infection subsided. The infection had not extended to the posterior mediastinum. When the patient was last observed, he still had a large fistula of the esophagus, and his condition still did not warrant barium studies to determine what type of reparative procedure would be required.

Case 5.—This patient was struck in the right shoulder and received a penetrating wound of the neck from an explosion of an antitank shell within an M–4 tank. Fluoroscopic examination revealed multiple foreign bodies in the base of the neck, one of them in the region of the right lateral wall of the esophagus. Extreme dysphagia was noted soon after the injury. The wound of entrance was debrided. No attempt was made to remove any foreign bodies.

The diet was limited to fluids, but intubation was not done. A week after injury, there was leakage from the wound of material taken by mouth, and when the patient was admitted to the 21st General Hospital, he had an esophageal fistula.

Intubation was immediately instituted, with high-caloric, high-vitamin feedings by this route. Nothing was permitted by mouth. The infection cleared rapidly, and the fistula closed with equal rapidity. Two weeks after admission, the patient's barium studies showed a normal esophagus.

Comment.—This case reemphasizes the importance of recognizing dysphagia as a possible symptom of a wound of the esophagus and of resorting to intubation at once in any instance of possible perforation.

CRUSHING INJURIES

Compression or crushing injuries of the chest observed in World War II were chiefly of noncombat origin. They varied considerably in extent, but they were usually relatively mild and required only conservative management.

The pathologic lesion varied according to the degree of trauma. It included simple contusion injuries of the pleura and lung; intrathoracic hemorrhage, subpleural in slight injuries and more central and more extensive in severe injuries; hemothorax; pneumothorax; fractures of the ribs and the sternum; rupture of viscera; and massive collapse of the lung. The so-called contusion pneumonia which followed severer types of compression injury and which could be extremely serious was in reality not a specific entity but the pneumonitis resulting from factors common in thoracic trauma. These factors included the limited respiration and cough caused by chest pain, retained bronchial secretions, and hemorrhage and edema of the lung. Together they made up the clinical picture of wet lung (p. 207).

In simple crushing injuries, the only treatment necessary was rest and relief of pain. In more severe injuries, the management of shock and the correction of disturbances of cardiorespiratory physiology resulting from hemothorax, pneumothorax, and emphysema were of primary importance. Surgery was necessary when lacerations of the diaphragm were present (p. 103). Penicillin was given, to prevent infection. Late complications included pneumonia, empyema, and lung abscess.

Ecchymotic Mask

Ecchymotic mask is the term used for the bluish-violet discoloration of the face, neck, and upper portion of the chest that sometimes results from sudden, direct compression of the chest or abdomen. In civilian practice, it is most often seen following compression of the chest between the rear end of a truck and a loading platform. It may also occur in sudden, direct compression of the extremities as the result of a fall or some other accident in which the thigh is violently flexed on the abdomen. In wartime, the casualty may be actually crushed by falling debris from bombs.

The discoloration may also be found in the pharyngeal and retrobulbar areas, though in these regions, true hemorrhage may have occurred. It is ordinarily more marked at areas of pressure, such as in the neck from collar-bands, around the head from hatbands, and across the shoulders from suspenders.

The explanation of ecchymotic mask is extreme stasis in the peripheral venous capillaries, which remain intact but become dilated. There is no evidence of diapedesis. The proof of the theory of stasis is threefold, (1) the intact state of the vessels; (2) the absence of extravasation of blood on microscopic examination; and (3) the absence of the usual shades of color observed as an ordinary ecchymotic spot gradually fades.

Clinically, the discoloration begins to fade about 48 hours after the injury and usually disappears in 2 weeks. The patients are seldom uncomfortable, and sequelae are unusual. Ocular symptoms, which are sometimes present, range from mildly blurred vision to total blindness. Fortunately, ocular involvement is uncommon, for retrobulbar or fundal hemorrhages may produce permanent atrophy of the optic nerve.

When Heuer (*6*), as the result of a personal experience in World War I, reported on ecchymotic mask, he was able to find 127 cases recorded in the literature up to 1923. There were 27 deaths immediately after injury and 8 deferred deaths. Autopsies were performed in 23 of the fatal cases. Symptoms and signs of intrathoracic injury were common, but they were generally slight and disappeared promptly. They included hemoptysis, pulmonary edema, hemothorax, pleural effusion with empyema, pneumonia, and subcutaneous emphysema.

Visual disturbances were reported in only 16 of the recorded cases, including Heuer's own case, but in 7 of these, there was permanent impairment or complete loss of vision, in all instances associated with progressive optic atrophy. In most of the recorded cases, there was no statement about the eyes, but in 23 reports, it was stated specifically that the eyes were not affected, and in 10 other cases, it can be assumed that they were not affected.

Ecchymotic mask was not often observed in World War II. It did not occur in any of the forward cases treated by the 2d Auxiliary Surgical Group,

which suggests that the causative factor is a product of localized thoracic crushing rather than the result of a penetrating or a blast injury. Major Burford, working in base hospitals, observed it only five times in 1,200 casualties. All of these were service troops, all were injured in jeep or truck accidents, and all recovered uneventfully.

Another textbook condition, commotio thoracis, was never observed by surgeons of the 2d Auxiliary Surgical Group, whose opinion was that it should be dropped from the list of traumatic entities.

BLAST INJURIES

Incidence

The British experience with blast injury was entirely gained through German bombings of the British Isles, a fact which, for a time, misled medical officers in the U.S. Army, who believed that they would encounter the syndrome frequently in combat. They did not. Blunt injuries of the intact chest, with resulting contusion, were fairly frequent, but blast injuries were uncommon. Early in the U.S. experience, the two conditions were frequently confused. Once the differentiation was appreciated and pulmonary edema from wet lung, injudicious fluid administration, and occasional fat embolism were also excluded, very few patients were seen in field or evacuation hospitals who could be considered to be suffering from true blast injuries of the chest.

The single case of blast injury observed by surgeons of the 2d Auxiliary Surgical Group in their 2,267 thoracic and thoracoabdominal injuries was confirmed by post mortem examination. The 8 cases observed by Maj. Frank Tropea, Jr., MC, and Lt. Col. John M. Snyder, MC, in 603 chest injuries resulted in 3 deaths; in 1 case, the diagnosis was confirmed by autopsy.

Capt. William W. Tribby, MC (7), in his study of 1,000 battlefield deaths of U.S. Army troops in Italy, found 13 bodies in which there were no penetrating injuries and in which the cause of death was presumably blast injury. In four cases, the diagnosis was confirmed at autopsy, which revealed diffuse pulmonary hemorrhage in all cases and pulmonary edema in three. Because of the advanced state of decomposition of the bodies, microscopic confirmation was possible in only one case.

Captain Tribby believed that several other casualties might also have died of blast injuries, for while penetrating wounds were present, they were not sufficient, in any instance, to account for the fatality. In one body, for instance, the only injury was a penetrating wound of the right wrist.

Data prepared by the Medical Statistics Division, Office of The Surgeon General, Department of the Army, show 1,021 blast injuries of nonbattle origin in the U.S. Army for the 1942–45 period, of which 48 were fatal (table 1). For the same period, there were 13,200 battle-incurred blast injuries outside of the

TABLE 1.—*Blast injuries of nonbattle origin in the U.S. Army, by numbers of admissions*[1] *and deaths,*[2] *and by area and year, 1942–45*

[Preliminary data based on sample tabulations of individual medical records][3]

Area	1942–45		1942		1943		1944		1945	
	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Continental United States	256	7	47	------	150	2	34	3	25	2
Overseas:[4]										
Europe	325	18	3	------	22	------	145	5	155	13
Mediterranean[5]	144	10	3	------	64	1	52	1	25	8
Middle East	4	------	1	------	3	------	------	------	------	------
China-Burma-India	11	2	------	------	2	------	4	1	5	1
Southwest Pacific	128	7	5	------	16	------	27	3	80	4
Central and South Pacific	119	4	9	------	22	------	18	------	70	4
North America[6]	20	------	4	------	12	------	4	------	------	------
Latin America	9	------	1	------	7	------	1	------	------	------
Total overseas	765	41	26	------	149	1	255	10	335	30
Total Army	1,021	48	73	------	299	3	289	13	360	32

[1] Includes an unknown, but presumably a relatively small, number of cases CRO (carded for record only), mostly deaths. For the two years, 1943 and 1945, in which the number of CRO cases was known, CRO cases constituted 3.2 percent of the nonbattle blast injury "admissions."

[2] Underlying cause of death, year of death, and area of admission.

[3] Complete files of records used for deaths, 1942 admissions, and oversea admissions in 1943. Samples of admissions were: 20 percent for 1945, U.S. 1943, and Europe 1944; 80 percent for 1944 excluding Europe.

[4] Includes 5 admissions aboard transports, 1 in 1943 and 4 in 1944.

[5] Includes North Africa.

[6] Includes Alaska and Iceland.

continental United States, of which 140 were fatal (table 2). Of the 6,284 blast injuries which occurred in 1944 and of which 76 were fatal, 493 involved the chest, and 25 of these were fatal (table 3). Another eight injuries, one of which was fatal, involved the thoracoabdominal region (table 3). Only 68 of the survivors in both groups (65 with thoracic wounds, 3 with thoracoabdominal wounds) required evacuation (table 4). A remarkable variety of agents (table 3) were responsible for these injuries, which are generally considered to be caused only by high explosives. It must also be remembered that deaths which occurred in blast injuries were not always due to those injuries. This was true in 3 of the 25 deaths which occurred in 1944.

To complete the picture, it should be added that, as might have been expected, the Navy experience with blast injury was considerably more extensive than that of the Army.

TABLE 2.—*Battle-incurred blast injuries in the U.S. Army, by numbers of admissions*[1] *and deaths,*[2] *and by area and year, 1942–45*

[Preliminary data based on sample tabulations of individual medical records]

Area	1942–45		1942		1943		1944		1945	
	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Europe	9, 651	106	1	-----	8	-----	5, 405	61	4, 237	45
Mediterranean[3]	1, 345	14	15	-----	462	-----	620	12	248	2
Middle East	1	-----	-----	-----	-----	-----	1	-----	-----	-----
China-Burma-India	16	-----	-----	-----	2	-----	8	-----	6	-----
Southwest Pacific	1, 455	12	10	-----	33	-----	176	2	1, 236	10
Central and South Pacific	715	8	8	-----	102	1	73	1	532	6
North America[4]	4	-----	-----	-----	4	-----	-----	-----	-----	-----
Latin America	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total[5]	13, 200	140	34	-----	616	1	6, 284	76	6, 266	63

1 Excludes cases carded for record only.

2 Among cases who reached a medical treatment facility. Underlying cause of death, year of death, and area of admission.

3 Includes North Africa.

4 Includes Alaska and Iceland.

5 Includes 13 admissions aboard transports: 5 in 1943 ,1 in 1944, and 7 in 1945.

Experimental Studies

The British experience with German bombings early in World War II led them to carry out a number of experimental studies on blast injuries of the lung, under the direction of the Research and Experiments Department of the Ministry of Home Security. The most important of these studies was reported by Zuckerman (*8*) in the *Lancet* of 24 August 1940. In the same issue, Dean and his associates (*9*) reported on the clinical aspects of these injuries, and in the issue of 19 October of the same year, Hadfield, Swain, Ross, and Drury-White (*10*) described the pathologic process as confirmed by autopsy studies.

Zuckerman's studies on blast injury, which are now classic, were carried out on pigeons and on animals varying in size from mice to monkeys. The experimental animals were exposed, in the open, (1) to blast from the explosions of 70 pounds of high explosives and (2) to explosions of hydrodgen and oxygen in balloons. Both sets of experiments produced essentially the same results.

In the experiments with high explosives, no animals were killed at distances beyond 18 feet, and none were hurt in any observed manner at distances beyond 50 feet. When the bodies were protected by thick layers of rubber,

TABLE 3.—*Battle-incurred blast injuries of the thorax and thoracoabdominal region, by numbers of admissions*[1] *and resulting deaths*[2] *in the U.S. Army, 1944, by area of admission and causative agent*

[Preliminary data based on sample tabulations of individual medical records]

Area	All agents		Artillery shell		Boobytrap, landmine, grenade, etc.		Bomb		Small arms fire		Other agents[3]	
	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
THORAX												
Europe	416	20	335	14	44	2	25	2	5	1	7	1
Mediterranean[4]	64	5	42	3	12	1	8	1	1	----	1	----
Middle East	----	----	----	----	----	----	----	----	----	----	----	----
China-Burma-India	----	----	----	----	----	----	----	----	----	----	----	----
Southwest Pacific	9	----	4	----	2	----	2	----	----	----	1	----
Central and South Pacific	4	----	3	----	1	----	----	----	----	----	----	----
North America[5]	----	----	----	----	----	----	----	----	----	----	----	----
Latin America	----	----	----	----	----	----	----	----	----	----	----	----
Total	493	25	384	17	59	3	35	3	6	1	9	1
THORACOABDOMINAL REGION												
Europe	5	1	2	----	3	1	----	----	----	----	----	----
Mediterranean[4]	3	----	2	----	1	----	----	----	----	----	----	----
Middle East	----	----	----	----	----	----	----	----	----	----	----	----
China-Burma-India	----	----	----	----	----	----	----	----	----	----	----	----
Southwest Pacific	----	----	----	----	----	----	----	----	----	----	----	----
Central and South Pacific	----	----	----	----	----	----	----	----	----	----	----	----
North America[5]	----	----	----	----	----	----	----	----	----	----	----	----
Latin America	----	----	----	----	----	----	----	----	----	----	----	----
Total	8	1	4	----	4	1	----	----	----	----	----	----

[1] Excludes cases carded for record only.

[2] Deaths occurring in 1944 among admissions in area indicated. Cause of death in 1 case (thorax, Mediterranean) was ascribed to compound comminuted fracture of scapula; in 2 cases (thorax, Europe) cause of death was ascribed to traumatic sucking pneumothorax.

[3] Includes some few with causative agent unknown.

[4] Includes North Africa.

[5] Includes Alaska and Iceland.

TABLE 4.—*Battle-incurred blast injuries of the thorax and thoracoabdominal region, by numbers of admissions [1] and resulting deaths [2] in the U.S. Army, 1944, by area of admission and evacuee status*

[Preliminary data based on sample tabulations of individual medical records]

Area	Total		Evacuated		Not evacuated	
	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths
THORAX						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Europe	416	20	63	--------	353	20
Mediterranean [3]	64	5	2	--------	62	5
Middle East	--------	--------	--------	--------	--------	--------
China-Burma-India	--------	--------	--------	--------	--------	--------
Southwest Pacific	9	--------	--------	--------	9	--------
Central and South Pacific	4	--------	--------	--------	4	--------
North America [4]	--------	--------	--------	--------	--------	--------
Latin America	--------	--------	--------	--------	--------	--------
Total	493	25	65	--------	428	25
THORACOABDOMINAL REGION						
Europe	5	1	3	--------	2	1
Mediterranean [3]	3	--------	--------	--------	3	--------
Middle East	--------	--------	--------	--------	--------	--------
China-Burma-India	--------	--------	--------	--------	--------	--------
Southwest Pacific	--------	--------	--------	--------	--------	--------
Central and South Pacific	--------	--------	--------	--------	--------	--------
North America [4]	--------	--------	--------	--------	--------	--------
Latin America	--------	--------	--------	--------	--------	--------
Total	8	1	3	--------	5	1

[1] Excludes cases carded for record only.
[2] Deaths occurring in 1944 among admissions in theater indicated. In 3 cases, not evacuated, death was ascribed to causes other than blast injury (see footnote 2, table 3).
[3] Includes North Africa.
[4] Includes Alaska and Iceland.

there was either no damage at all, or minimal damage, as compared to the damage suffered by control animals. This observation, it might be interpolated, furnishes additional evidence for the use of body armor.

None of the animals or birds had any external signs of injury. In every autopsy, the outstanding finding was traumatic pulmonary hemorrhage, which varied in degree according to (1) the distance of the animal from the charge and (2) the pressure exerted against the body. The lesions were bilateral unless the animals were so placed that one side acted as a shield for the other.

Then the lesions occurred on the side facing the explosion. This fact, as well as the anatomic sites of the hemorrhage, permitted no interpretation except that the lesions were caused by the impact of the pressure wave against the body wall. In all instances in which the lung injury was sufficiently severe to cause death, the lesions were detectable on roentgenologic examination, and blood was present in the upper respiratory passages as well as in the lungs.

Mechanism

Blast may be defined as the compression and suction waves set up by the detonation of a charge of high explosive. At every point in the neighborhood of the explosion there occur:

1. A wave of high pressure, lasting about 0.006 second, according to Zuckerman's studies with 70-pound charges, followed by
2. A negative suction pressure wave, lasting up to 0.003 second, produced by the reduction of the density of the air behind the positive compression wave to below the normal atmospheric pressure, which is about 15 pounds per square inch. The suction component of the blast wave is always much weaker than its pressure component; it can never be greater than 15 pounds per square inch, which corresponds to a perfect vacuum. It is only because of the very short duration of both components that blast waves are not more destructive than they are.

As hot gases are ejected by a detonating shell, they compress the surrounding air into a shell or belt, which is thrown against adjacent layers of air. The compressed air within the belt is characterized by high pressure and high outward velocity. It is limited by an extremely sharp front, the so-called shock front, which is less than one-thousandth of an inch and in which the pressure rises abruptly.

The initial velocity of the shock front as it travels away from the point of detonation is extremely high. Maj. Ralph W. French, MAC, and Brig. Gen. George R. Callender (*11*) estimated it as 3,000 feet per second at 60 feet from a 4,000-pound light-case bomb where the pressure jump is 100 pounds per square inch. The velocity then decreases rapidly down to the velocity of sound, which is about 1,100 feet per second or 750 miles per hour. The velocity of the shock front can be realized by comparing it with the velocity of gale winds from 50 to 60 miles per hour; of hurricanes, 80 to 100 miles per hour; and of tornadoes, in which estimated velocities range from 200 to 230 miles per hour.

Because the pressure wave is highest in the region of the explosion and falls off rapidly the farther it moves from it, everything in the immediate neighborhood of a bomb explosion will suddenly be exposed to violent pressure waves of many times atmospheric pressure, while everything 50 feet or more away will be exposed to only two or three times atmospheric pressure. The

746-941v—65——5

velocity and duration of a pressure wave at any given point are such that any object as large as the human body would undoubtedly be completely immersed for an instant in a wave of almost uniformly raised pressure.

The magnitudes of the pressure and suction components of a blast wave are directly correlated with the amount of explosive. Zuckerman's studies showed, however, that if a given positive pressure is caused by a given amount of explosive at a given distance, the same degree of pressure will be experienced at twice that distance only when the amount of explosive is increased eight times.

Thus all objects in the immediate neighborhood of an explosion are first subjected to violently increased wind and hydrostatic pressure, which may tear them to pieces and blow them far from the scene of the explosion. If they are not shattered by the pressure wave and blown along in its direction, they may be pulled toward the center of the explosion by the weaker, but longer acting suction wave.

Pathologic Process and Causes of Death

The pathologic process which results from the contusive effect of a blast wave on the chest arises, according to Zuckerman's (*8*) experimental studies, from the pressure component of the blast, which bruises the lungs by its impact on the body wall. It varies from small ecchymotic areas on the lung surface to such extensive lesions that the lung may appear hepatized.

In the 10 autopsies performed by Hadfield and his associates (*10*) on civilians who died suddenly, or within a few hours, after short-range exposure to detonation of high explosives during aerial bombings, gross traumatic lesions were entirely absent or were trivial in all but one instance. In eight cases, death was due to the effects of blast, though in three cases carbon dioxide saturation of the blood was so extreme that it was considered the immediate cause of the fatality. Two casualties who were extricated from overlying debris without visible injuries were first thought to have died of blast. Further examination showed that both deaths were caused by compression asphyxia.

As in Zuckerman's experimental studies, intrapulmonary capillary hemorrhage was the single gross anatomic lesion common to all cases in which deaths were due to blast. There was free capillary bleeding over large areas, and in these areas, the bronchioles, atria, and alveoli all showed uniform and considerable overdistention. In the fatalities due to compression asphyxia, hemorrhage was relatively slight. In these cases, the air passages contained only a small amount of blood-stained fluid, which was not frothy, but capillary and venous congestion and edema were striking. In the fatalities due to carbon dioxide saturation, the pulmonary hemorrhage was of the same character as in the true blast deaths, but the blood was fresh and pink, not dark. In both groups, the air passages contained quantities of frothy, serous fluid. Tribby (*7*) noted that in all 13 cases in which he believed death on the battlefield to be due to blast, there was blood in the nose or mouth or in both in every instance.

Subpleural hemorrhage was not conspicuous in the blast deaths studied by Hadfield and his group (*10*). The only casualty in the series who showed hemorrhagic rib markings in the pleura died from compression asphyxia, not from blast. Bleeding into the walls of the smaller bronchioles was occasionally observed, but there was a conspicuous absence of hemorrhage into the larger structures. There was no suggestion that hemorrhages were grouped around the bronchial system. Subpleural bullae, observed microscopically, had apparently been produced by detachment of the visceral pleura and its subjacent elastic tissue from the underlying lung by air escaping from ruptured alveoli.

The most severe hemorrhages were found in two young children, one an infant, the other 13 years of age; the possible explanation was the lesser rigidity of the thoracic wall in youth. Bleeding was minimal in the only notably obese casualty in the group; it may be presumed that his excess flesh protected him from the most serious effects of the blast.

Even making due allowance for the rapidity of the extravasation of blood into the lungs as the result of blast, in no instance was the amount of blood found at autopsy sufficient to cause fatal circulatory embarrassment. The conclusion was that blast probably produces death by interference with some vital tissue or center, in which, because of the extreme rapidity of the process, the structural changes that occur are not detectable. Hadfield and his associates (*10*), however, considered the presence of hemorrhage a trustworthy indication that the patient had been struck at close range by a wave of high pressure.

In general, autopsy studies on victims of blast in the Mediterranean theater were in accord with these observations (fig. 10).

Clinical Picture and Diagnosis

Symptoms and signs.—The clinical symptoms and signs of blast injury as observed in World War II were as follows:

1. *Shock.*—This was a universal finding and was often profound. As a rule, the degree of shock was directly proportional to the severity of the injury. It was often increased by, or was more serious because of, associated injuries in other parts of the body.

2. *Restlessness.*—This finding was often extreme and out of proportion to the evident severity of the injuries.

3. *Chest pain, which was of two types.*—Almost all casualties from blast complained of pain located laterally and related directly to respiratory movements. This type of pain was considered due to contusion and hemorrhage of the intercostal muscles, with resulting muscular spasm. The other type of pain appeared in the more severe injuries. It was deep, central, and not related to respiratory movements. It lasted only a few days and was considered to be caused by mediastinal hemorrhage.

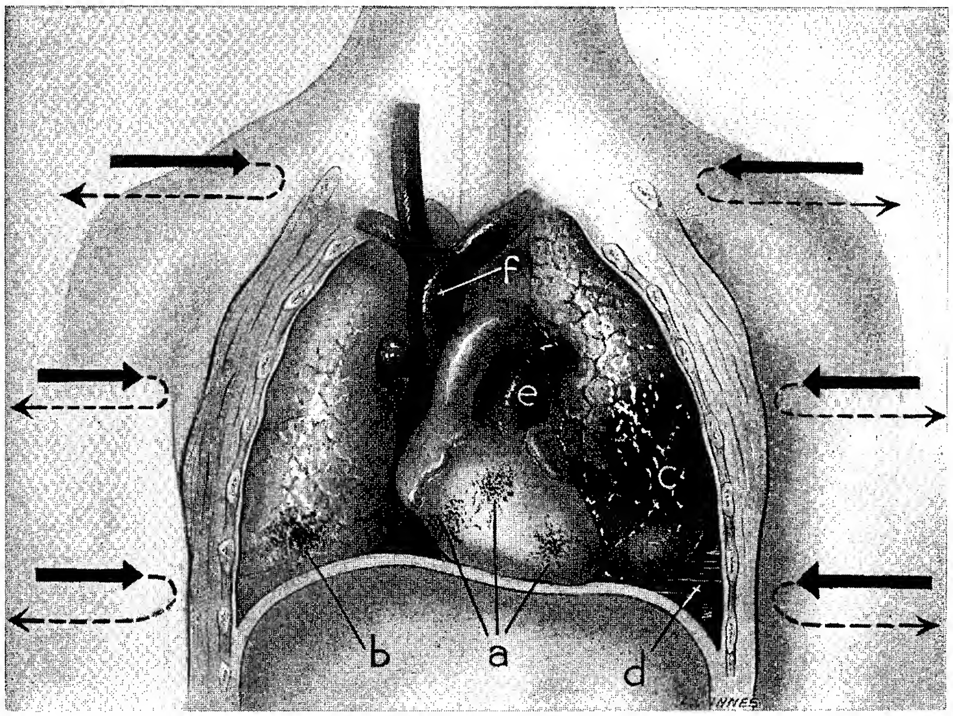

FIGURE 10.—Schematic showing of pathologic physiology of blast injury (wave of positive pressure shown by solid arrow, wave of negative pressure by dotted arrow): Petechial hemorrhage, cardiac (a), petechial hemorrhage, pulmonary (b), gross pulmonary hemorrhage (c), pleural hemorrhage (d), engorged pulmonary artery (e), and engorged vena cava (f).

4. *Cough and expectoration, which were present in all but the mildest injuries.*—When the expectorated material first appeared, about 24 hours after injury, it was thin and mucoid. Later, it became thick and mucopurulent. Often, it was streaked with dark blood, and in an occasional case, there was free hemoptysis. Expectoration usually lasted about 10 days. Almost all dead or dying casualties were found to have frothy, blood-stained fluid in the nose and mouth.

5. *Abdominal pain and rigidity.*—These findings, which were present in only a few blast injuries, were explained by extrapleural hemorrhages, which had an irritative effect on the intercostal nerves and muscles. In an occasional case, the persistence and prominence of these findings provided an indication for laparotomy.

6. *Partial fixation of the chest in the position of inspiration.*—Movement, although limited, was equal on both sides.

In the absence of complications, the percussion note was resonant. Breath sounds were usually weaker than normal, especially at the bases, and coarse bronchial rales were frequently heard in both lungs.

These observations are, in general, in correspondence with those reported by Dean and his associates (*9*) in 27 patients whom they examined from 7 to 10 days after they had been close to bursting high explosive bombs. Three of the casualties had been immersed. External injuries included extensive, but superficial, burns in 21 cases; fractures in 5 cases; and multiple splinter wounds of the leg in 1 case.

There were no obvious chest injuries, and only six patients had symptoms referable to the chest. None complained of chest pain or hemoptysis. In no instance did the symptoms develop on the day of bombing; all appeared between the second and fifth days. Sixteen patients had abnormal physical signs, in 15 instances the characteristic fixation of the chest just described; in 1 instance the intercostal spaces shared the fullness.

Roentgenologic examination.—If the classical pathologic picture was present, roentgenograms showed heavy mottling over large areas of the lung fields, corresponding with the interstitial and alveolar hemorrhages observed, and varying in size and density with the extent of the lesions. The roentgenologic findings suggested those observed in patchy pneumonia. They disappeared within a week in mild injuries but persisted for weeks in severe injuries. Roentgenologic abnormalities were present in 14 of the 27 patients studied by Dean and his associates.

Diagnosis.—The first consideration in a suspected blast injury was a history of exposure, which, in spite of its importance, had to be interpreted with caution. The effects of blast were often a factor in wounds from high explosives, but the seriousness of the penetrating wounds was likely to overshadow them.

Other diagnostic criteria consisted of the presence of shock; the various respiratory symptoms described; the characteristic bulging of the lower portion of the chest, which was held almost immobile in the inspiratory position; and the finding of blood in the lungs and air passages. Ruptured eardrums were pathognomonic. Roentgenologic findings were confirmatory.

The essential features of diagnosis were:

1. The absence of any significant external evidence of violence to the chest.
2. Hemorrhagic lesions in both lungs, as shown by the character of the fluid expectorated or, less often, by hemoptysis, or by autopsy confirmation.

Management

The management of blast injury was never really satisfactory. The routine consisted of the following measures:

1. *The treatment of shock.*—However deep was the state of shock and however much associated injuries demanded intensive measures, resuscitation had to be carried out cautiously from the standpoint of replacement therapy. Injudicious use of any fluid, including blood, might increase pulmonary edema. An occasional patient, in fact, in whom edema and congestion were particularly marked, responded to venesection, which was employed as a lifesaving measure.

Some medical officers, in order to reduce the amount of fluid infused, administered serum albumin in 100-cc. doses every 4 hours for three or four doses.

2. *The continuous administration of oxygen.*—This measure was used especially if cyanosis was a feature of the injury, or intermittent positive pressure oxygen.

3. *The cautious use of morphine.*—Morphine was used on strict indications and in doses of not more than gr. 1/8 if pain could not be controlled otherwise.

4. *Positioning.*—Since the bases of the lungs were usually involved in the hemorrhagic process, the best position was with the shoulders raised. In the occasional instance of unilateral blast injury, the patient was placed on the damaged side, to keep the blood from trickling down the bronchi into the unaffected lung.

5. *Local nerve block.*—This measure was employed to control pain and permit free respiration.

6. *Other medication.*—The administration of adrenalin was not without risk, but it was occasionally used to overcome a temporary spasm of the bronchioles. Atropine was also occasionally used to diminish exudation. A sulfonamide, or penicillin when it became available, was used as preventive measure.

If surgery was necessary for other wounds, it was postponed as long as possible, and then was done under local analgesia or with Pentothal sodium (thiopental sodium). General anesthesia was avoided.

Case History

The following case history concerns the only valid blast injury recorded in the experience of the 2d Auxiliary Surgical Group:

Case 6.—This soldier was riding in the back seat of a command car when the rear wheels ran over a landmine. When he recovered consciousness some minutes later, he was lying on the ground, beside a tree. His only complaint was a bilateral hearing impairment. Speech and cerebration were not impaired, and he had no dizziness, headache, or blurred vision. The only external wounds were a small puncture wound anterior to the left ear, near the temporal artery; a compound fracture of the right ankle; and a simple fracture of the left ankle.

Wire splints, extending above the knee, were applied in a collecting station. Later, the wound of the right leg was debrided, and plaster casts were applied to both legs.

When the patient was admitted to the 38th Evacuation Hospital, 52 hours after injury, he was in good condition, was talking rationally and normally, and had no complaints. Both pupils were equal and regular. The toes on both sides were warm.

Four hours after admission, the pulse rate began to range between 125 and 130. A little later, it rose to 140; at this time the respiration was 32 and the blood pressure 98/60 mm. Hg. After 500 cc. of plasma had been given, the pulse fell to 120, and the blood pressure was 98/50 mm. Hg. The respiration was 40 and the temperature 100.4° F. The patient was very drowsy, but he could be aroused, and he was then mentally clear.

After a brief interval, his condition rapidly worsened; the blood pressure dropped, and the pulse rate became very rapid. After the foot of the bed had been elevated and 500 cc. of blood and 750 cc. of plasma had been given, the systolic blood pressure was recorded at 100 mm. Hg, but the diastolic pressure could not be obtained. Shortly afterward, the systolic pressure fell to 70 mm. Hg.

About this time, moderate respiratory distress developed, and the patient began to spit up frothy blood. The breath sounds were spottedly distant, and coarse rales were heard over the entire chest. There was considerable consolidation of both bases, with a marked friction rub. The upper abdomen was distended, and no peristalsis could be heard. Voiding was involuntary.

Respiratory distress increased rapidly, and the patient became slightly cyanotic. Frothy fluid, streaked with bright red blood, was being expectorated. After the administration of two ampules of Coramine (nikethamide) and 500 cc. of blood, examination of the chest revealed diminished breath sounds and tactile fremitus on the left, with a loud to-and-fro friction rub. Oxygen therapy was instituted. The blood pressure was now 90/40 mm. Hg. The patient, although struggling for breath, remained lucid enough to answer questions. His dyspnea did not seem of the obstructive type.

Death occurred suddenly, 72 hours after injury and 24 hours after admission to the evacuation hospital. There was no response to artificial respiration.

Autopsy disclosed an entirely clear peritoneum and retroperitoneal space. The thoracic cage and diaphragm were intact, as were both pleural cavities.

The lungs were expanded, and there were numerous areas of hemorrhage and crepitation. There was no blood in the pleural cavity, but when the bronchial tubes were sectioned, they were found to contain frothy, serous fluid. The heart was grossly normal except for a questionable auricular thrombosis. The thrombi in the pulmonary artery were regarded as a post mortem development.

Histologic examination of the lungs showed extensive areas of intra-alveolar extravasations of red cells intermingled with varying numbers of pigmented macrophages. Occasional alveoli were filled with fluid containing a few red cells. Other alveoli, some emphysematous, were interspersed among them. Some of the emphysematous alveoli had ruptured walls. The bronchial lumen contained large numbers of red blood cells.

The gross pathologic diagnosis (in addition to the fractures of the lower extremities) was possible blast injury of the lung, possible thrombosis of the pulmonary artery, and possible thrombosis of the cardiac auricle. The histologic diagnosis was severe pulmonary hemorrhage, ruptured alveoli, congestion of the spleen, and epicardiac hemorrhage.

Comment.—This injury was difficult to evaluate from the clinical standpoint, and the diagnosis of blast syndrome was not made early enough for therapy to be precise and effective. One can only speculate whether earlier recognition of the blast injury, with intensive treatment directed toward it, would have altered the outcome.

Unfortunately, no special fat stain was used on the tissues. In some blast injuries, fat emboli were found in the lungs, as they were in some compound fractures; they were more often seen after traumatic amputations from landmines. The diagnosis of blast injury of the lungs was made in this case on the basis of the ruptured alveoli.

ASSOCIATED WOUNDS

A large proportion of thoracic injuries, as pointed out elsewhere (vol. I), were associated with injuries in other parts of the body, and these associated injuries were frequently more serious than the chest injuries. That other injuries might exist had to be taken for granted in the approach to all chest injuries. In other words, regardless of how specialized or restricted an injury might seem, a total therapeutic approach was necessary. In caring for a casualty, the surgeon had to conceive of him as a total organism, not as an assembly of individual injuries. The management of the chest injury therefore had to be related to the management of all other injuries.

Compound Fractures

Compound injuries of the scapula and shoulder girdle might furnish numerous problems. A missile of high velocity that struck the scapula a glancing blow could cause extensive damage to the heavy muscles in the vicinity, in addition to shattering and fragmenting the bone. Although there was always considerable question as to how radical one should be in dealing with fractured ribs, there was rather general agreement that fractures of the scapula, especially subscapular fractures, because of the less adequate drainage possible in this area, required more radical management than fractured ribs in other locations. Infection invariably resulted if the initial debridement was not complete. Wide excision of the damaged muscles was necessary, because of the great danger of anaerobic cellulitis in this area.

Fragments of the alar portion of the scapula, if left in situ, almost invariably led to continued suppuration. Even when the scapula itself was not damaged, it was necessary to bear in mind the possible involvement of the subscapular space when reconstruction of the course of a missile that had penetrated the chest wall indicated this possibility. Abscesses in this area could remain unrecognized for long periods of time.

Debridement, to be entirely adequate, would have required an incision approaching in magnitude the incision necessary for thoracoplasty and would also have required mobilization of the scapula. Such radical measures could not be justified on the mere possibility that a clostridial infection might develop. The usual procedure was to make the incisions along the track of the missile at the vertebral and axillary borders of the scapula, then to perform as complete a debridement as the exposure permitted. Great care had to be taken during surgery in this area not to disturb the attachment of the serratus anterior; damage to it could be followed by serious functional losses. As much as possible of the scapula was preserved, particularly of the functionally important upper third. Less hesitancy was felt about removing as much as necessary of the lower two-thirds. Through-and-through Penrose drains were inserted, and a dependent drain was placed in the subscapular space through an incision in the angle of auscultation at the interior border of the scapula.

The patient was kept in the forward hospital in which operation had been done for at least 6 days after operation. The wound was examined immediately if there was a rise in the pulse rate or if he complained of local pain or if his demeanor changed, as it characteristically does in clostridial infections.

In six cases treated by the technique just described, Major Shefts and Capt. (later Maj.) Ernest A. Doud, MC, had no deaths. On the other hand, Maj. (later Lt. Col.) Reeve H. Betts, MC, and Maj. William M. Lees, MC, lost a patient from clostridial infection after what was thought to be a very radical debridement. It was their custom thereafter to use large paravertebral incisions in injuries of the subscapular area, even though intrapleural damage had not occurred.

When fractures ordinarily treated by traction occurred in association with wounds of the chest, some compromises in therapy were necessary. Prolonged immobilization in traction was inimical to satisfactory progress in chest injuries. The patient had to be kept maneuverable. Precise fracture alinement could not be achieved at the expense of thoracic crippling. Fortunately, the orthopedic repertoire was extensive enough and flexible enough to permit the application of a regimen that would reduce the fracture satisfactorily without jeopardizing the outcome of the chest lesion.

Vascular Injuries

Injuries to the great vessels of the axilla and at the root of the neck were not always recognized at initial wound surgery for chest injuries, and careful observation was necessary in base hospitals. Otherwise, important delayed sequelae of the vascular injuries might be overlooked. It was particularly necessary to be suspicious whenever the point of entry of the missile was over the apical region of the thorax. In one such case (p. 244), on the basis of roentgenologic examination and the repeated aspiration of clotted blood from the chest, the casualty, who had sustained a penetrating wound of the right apical region 3 months before, was thought to have only a hemothorax. His progress was satisfactory until he had a sudden attack of dyspnea and pain in the right chest. Soon after, he went into profound shock and died promptly. Necropsy revealed a rupture of a traumatic aneurysm of the first portion of the right subclavian artery.

It was always necessary, when operation was undertaken for early massive empyema or clotted hemothorax, to remember the possible presence of a traumatic aneurysm of the subclavian artery, as in the case just described, or of the innominate artery. Ignorance of the presence of the vascular lesion could easily result in catastrophe on the operating table.

In a case observed by Major Brewer at the 21st General Hospital, the patient, who had a foreign body in the chest wall, was conscious of a bruit that caused him considerable annoyance. It also made him so apprehensive that he was afraid to perform even moderate activity. A thrill was present, but there was no erosion of the rib and no cardiac embarrassment. A large hemothorax had previously been completely evacuated by repeated thoracenteses. After a diagnosis had been made of aneurysm of the intercostal artery and vein, the lesion was excised, for prophylactic reasons, and the foreign body in the chest wall was removed. The patient was able to return to full duty. It is believed that this is the only case of the kind to be observed in the Mediterranean theater during the war.

If ligation of the subclavian or axillary vessels had been necessary in a forward hospital, thoracic surgeons in general hospitals had to determine whether or not an adequate collateral circulation existed. Measures to maintain the circulation, or to increase it if it was deficient, were imperative.

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The most useful measures to control edema were proper positioning of the hand and arm; intelligently applied massage; and procaine hydrochloride block of the inferior cervical ganglion, repeated every 24 to 48 hours as necessary.

As a rule, casualties with arteriovenous fistulas resulting from combined thoracic-vascular injuries were evacuated to the Zone of Interior for final surgery. If, however, evacuation was delayed for an inordinately long period and compression tests revealed a satisfactory collateral circulation, operation was done overseas. Quadruple ligation with excision was the procedure of choice.

Neurologic Injuries

Brachial plexus.—The injuries of the brachial plexus frequently associated with chest injuries constituted a neurologic problem. Careful examination in both forward and base hospitals was necessary in every chest injury, to determine their presence or absence. It was often impossible to settle this matter positively in the first few days after injury; during this period, the neurologic findings present might be caused by contusion of the nerve as well as by laceration. If the injury was only a contusion, sensation and function would return promptly.

Head injuries.—Head injuries were frequently associated with thoracic injuries, and patients with head injuries were particularly prone to chest complications. Atelectasis and pneumonitis were ever-present threats, particularly in patients who were deeply comatose. Chest surgery was kept to an absolute minimum in these circumstances. Careful nursing, drainage of the tracheobronchial tree by catheter and bronchoscope, and the administration of penicillin were all employed to avoid serious and fatal pulmonary complications.

Spinal injuries.—In one series of 768 chest injuries studied by the 2d Auxiliary Surgical Group, there were 23 spinal cord injuries. Fractures of the vertebrae were also frequently associated with war wounds of the chest.

Roentgenologic examination of the spine was routine whenever there was any complaint of pain in the back or the cervical region. Some injuries were detected only when the patients became ambulatory; they had fallen or been thrown with considerable force when they were injured, and the simple vertebral fractures they had sustained were not noticed during their initial treatment because of the greater importance of other injuries.

Associated injuries of the chest and the spinal cord constituted one of the most distressing complexes seen in war surgery. The close anatomic juxtaposition of the structures of the spine and thorax made it inevitable that major injuries should affect both regions in a considerable number of cases. Casualties with these so-called thoracospinal wounds were open to the complications inherent in both lesions. There was a marked predilection for paralyzed patients with chest wounds to develop infection of either the pleura or the

pulmonary parenchyma. Hemothoraces were much more likely to become infected than in patients without spinal cord lesions.

The most important component of management of these combined injuries was intelligent nursing care (*12*). Patients were nursed in the face-down position, whenever this was practical, and were turned at frequent intervals, to prevent the development of decubitus ulcers. Air mattresses were used when they were available. Coughing and breathing exercises were carefully supervised. Repeated thoracenteses were performed, to dry up the pleural cavity as rapidly as possible. If empyema developed rib-resection drainage was usually employed; these patients were seldom in condition for the more radical procedure of decortication.

Patients with combined spinal cord-thoracoabdominal injuries were particularly difficult to care for. Many of the wounds were tangential, a type likely to be associated with far more pulmonary contusion and damage than the average penetrating or perforating wound. It was impossible for the patients to cough effectively because of paralysis of the lower intercostal and abdominal muscles. The flared costal angle, the segmental motion of the chest wall, the relaxed abdomen, and the feeble bechic blast were all characteristic of these combined wounds. In many cases, tracheobronchial aspiration was necessary as often as every 1 to 3 hours. Contrary to the usual observation, support of the abdomen and lower ribs by binders or adhesive strapping seemed to make coughing more efficient.

It was observed in certain patients with combined injuries of the chest and spinal cord that the level of anesthesia caused by the spinal injury seemed to play a considerable part in the outcome from the standpoint of the chest injury. Death sometimes occurred from intractable pulmonary edema. There was no response to positive pressure oxygen therapy or endotracheal suction, even though the chest wounds were not in themselves potentially lethal.

Analysis of a number of these fatalities led to the conclusion that the lethal factor was paralysis of the abdominis recti muscles. Normally, the tone of the recti in a gentle cough, or their actual contraction during a vigorous cough, provides the diaphragm with opposing intra-abdominal pressure. When the pressure was lost by reason of paralysis of the recti, the cough became ineffective; the expulsive action resulted in nothing more than bulging outward of the abdomen; and intractable pulmonary edema was the consequence.

This chain of events was clear in two of four cases of combined spinal cord-chest injuries treated in a field hospital in the Mediterranean theater by Major Shefts and Captain Doud. All four patients presented a typical picture of transverse myelitis, and all had pleuropulmonary damage of about the same degree. The two fatalities were directly related to the level of cutaneous anesthesia. They occurred 4 and 5 days, respectively, after debridement of the chest wounds, from pulmonary edema that did not respond to any measures, including positive pressure oxygen and endotracheal suction. One patient had anesthesia from below the xiphoid process and the other from just below

the nipples. The two patients who survived had skin anesthesia below the umbilicus, one just below the umbilicus and the other halfway between the umbilicus and the symphysis pubis.

While a defeatist attitude was never permitted in combined spinal cord-thoracic injuries, it would have been unrealistic not to recognize their potential lethality. In many cases, therefore, the frank objective of treatment was to salvage these unfortunate men long enough to permit them to be returned to the United States, so that they could spend their remaining days at home and with their families. This was possible in many of the most apparently hopeless cases.[2]

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[2] The reader is referred to chapter XI (p. 441) for long-term followup studies of the various types of wounds described in this chapter.

CHAPTER II

Wounds of the Heart (Including Retained Foreign Bodies), Mediterranean (Formerly North African) Theater of Operations

Lyman A. Brewer III, M.D., and Thomas H. Burford, M.D.

INCIDENCE

In World War I, as Makins (*1*) pointed out, casualties with cardiac wounds who survived to come under the care of a surgeon were hit either by relatively small missiles or by missiles traveling with reduced degrees of velocity. The same situation prevailed in World War II. In the 2½ years that elapsed between the first Allied landings in North Africa on 8 November 1942 and the end of hostilities in Italy on 2 May 1945, only 75 of the 2,267 thoracic and thoracoabdominal wounds encountered by the teams of the 2d Auxiliary Surgical Group were instances of cardiac or pericardial injury. This is an incidence of 3.3 percent. Of the 75 injuries, 18 were examples of pure pericardial trauma. In the other 57 cases, the heart was involved (table 5). No single team encountered more than 10 cases.

In 1 of the 75 cases, the only stab wound in the series, the wound was self-inflicted. The remainder of the injuries were all battle-incurred, in 53 instances from shell fragments and in 21 from small arms fire. In 2 of the 18 pure peri-

TABLE 5.—*Distribution of injuries and anatomic involvements in 56 combat-incurred cardiac injuries* [1]

Type of injury	Cases	Anatomic involvement						
		Ventricles			Auricles		Both	
		Right	*Left*	*Both*	*Right*	*Left*	*Right*	*Left*
Contusions	16	5	7	3	1	------	------	------
Lacerations	10	2	7	------	1	------	------	------
Contusions and lacerations	10	2	5	2	------	------	1	------
Perforating or penetrating	19	3	7	------	7	2	------	------
Embolic to heart	1	------	1	------	------	------	------	------
Total	56	12	27	5	9	2	1	------

[1] This table does not include a self-inflicted stab wound, from which the patient recovered. It also does not include 18 combat-incurred pericardial injuries, 3 of which were fatal.

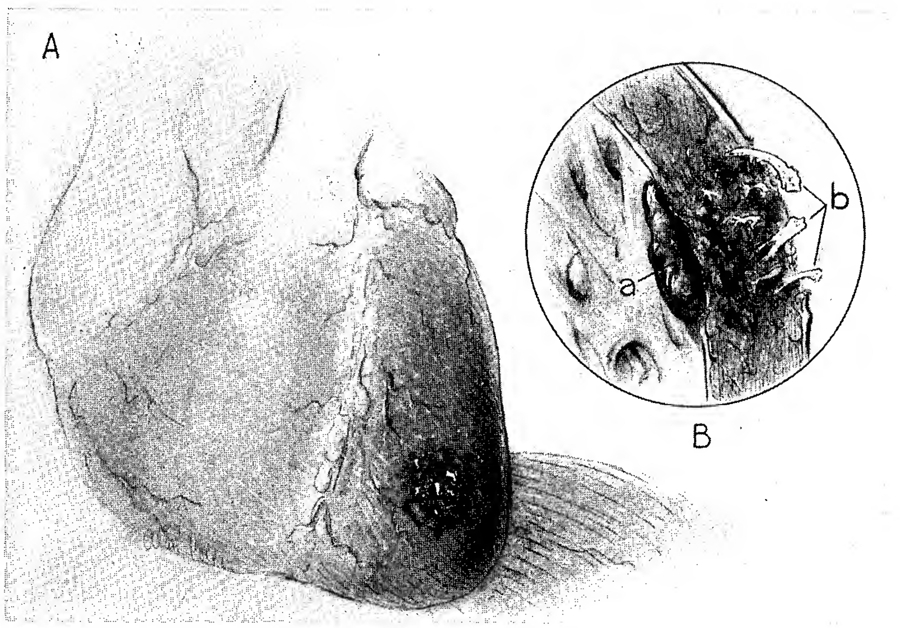

FIGURE 11.—Fatal cardiac contusion. A. Specimen without extensive pericardial damage. B. Cross section showing endocardial thrombi (a). In this case, rib fragments acted as secondary missiles (b).

cardial injuries, the damage was caused directly by rib fragments, and in at least 1 other case, extensive contusion of the myocardium was caused by rib fragments which acted as secondary missiles (fig. 11). In 43 cases, the injuries were confined to the chest; in the other 32 cases, the wounds were thoracoabdominal.

As these statistics indicate—75 cardiac wounds in 2,267 thoracic and thoracoabdominal injuries—wounds of the heart were not observed with any great frequency in forward hospitals of the Mediterranean theater. The reason, as already intimated, is that they were usually—though not always (fig. 12)—promptly fatal. These figures take no account of immediately fatal wounds, nor do any reliable statistics exist concerning them. In the analysis of 1,000 battlefield deaths by Capt. William W. Tribby, MC (*2*), it did not prove practical to perform routine autopsies, and even this remarkable series therefore contributes nothing really definite concerning the number of casualties with cardiac wounds who died on the field.

It should be remembered in reading this chapter that, as will be discussed in more detail later, in every instance in this series, the cardiac injury was only a single feature of the trauma. In addition to their cardiac injuries, all of these casualties had sustained more or less extensive wounds of adjacent thoracic structures, and the chest wounds in many instances were further complicated by serious wounds of other parts of the body.

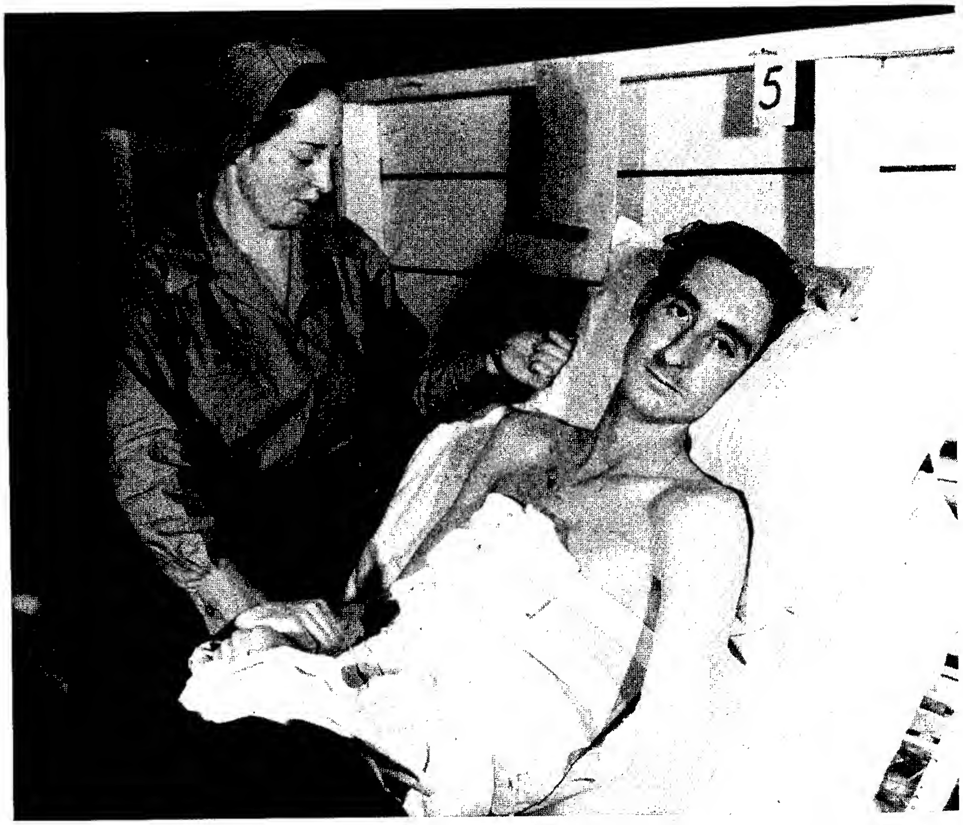

FIGURE 12.—Survivor of cardiac wound shortly after machinegun slug had been removed from his heart. He went on to complete recovery.

The data in these cases, most of which were cared for under stress of battle conditions in forward hospitals, are remarkably complete, thanks to the special records kept by the teams of the 2d Auxiliary Surgical Group. The preservation of essential data, including roentgenograms and electrocardiograms, was facilitated by the peculiar and often dramatic nature of the injury, which attracted the attention of shock officers and internists as well as surgeons. Personal notes on the records, and personal comments by the medical officers who cared for the patients, provided more information in these cases than was usually obtainable from even specially kept clinical records.

CLINICAL PICTURE AND DIAGNOSIS

Diagnostic Considerations

The preoperative diagnosis of injuries of the heart was not only difficult in itself but was sometimes not made because examination was not directed toward their discovery. One reason for the omission was the impression that

casulties with cardiac wounds did not live long enough to arrive at a forward hospital. As a result, symptoms and signs arising from the cardiac wound, particularly anoxia, were often attributed to other injuries that were present and that complicated the diagnosis. There is no doubt that more careful clinical examinations would have led to an increase in correct diagnosis. It is significant that the same three medical officers made all seven observations of arrhythmia in the 2d Auxiliary Surgical Group series. As with anoxia, the relation of tachycardia to the cardiac wound had to be based on ruling out all other causes for this sign. No single symptom or sign was usually sufficient to establish the diagnosis of cardiac injury.

The patient was usually designated for surgery on the suspicion of a thoracoabdominal wound, or the cardiac wound was found in the course of traumatic thoracotomy or during debridement of a large sucking wound, or it was searched for because of continued intrathoracic bleeding during the course of presumably adequate resuscitation. In 15 of the 75 cases in the 2d Auxiliary Surgical Group series, the injury was discovered at post mortem. In a few cases, it was found, in retrospect, that the symptoms and signs recorded on the chart should have aroused suspicion before operation or autopsy.

Symptoms and Signs

Symptoms and signs were divided into two groups, symptoms due to anoxia and signs suggestive of cardiac dysfunction.

In this series, six patients were recorded as dyspneic, six as needing continuous oxygen, five as mentally confused or semistuporous, and three as cyanotic. Before these findings could be attributed to a cardiac wound, however, other causes of oxygen deficiency, such as hemorrhage, hemothorax, compression pneumothorax, and extensive peritoneal contamination, had to be ruled out. When these conditions had been eliminated and symptoms due to anoxia persisted out of all proportion to visible thoracic damage, then there was justification for regarding them as due to a cardiac lesion.

Signs suggestive of cardiac dysfunction included persistent tachycardia (a pulse of 120 or above) in eight cases, arrhythmia in seven cases (transient fibrillation in one and extrasystoles in six), bradycardia (a pulse below 65) in two cases, an apical systolic murmur and a precordial friction rub in two cases each, a paradoxical pulse in one case, and nausea and vomiting in one case.

Both precordial friction rubs were heard for the first time 24 hours after injury; operation was delayed 3 days in one case and 5 days in the other. Since a friction rub or splash was noted in eight additional cases after operation, it was concluded that a certain length of time must elapse after wounding before this sign appears. The explanation of this phenomenon is the presence in the pericardium of air and fluid. It was seldom seen because, in most instances, the pericardial fluid had drained into the pleural cavity before surgery.

The single instance of paradoxical pulse occurred in a patient with severe myocardial contusion, who died in the shock ward. The persistent nausea and vomiting noted in one case was uncommon in thoracic wounds and led to the suspicion of a thoracoabdominal wound. Whether or not it was caused by the cardiac wound, it was associated with it and made for further diagnostic difficulties.

A precordial crunch or click was occasionally heard, synchronous with the heartbeat. It was associated with mediastinal emphysema and was not considered related to the cardiac trauma.

In retrospect, the most important diagnostic findings were considered to be:

1. A sustained pulse of 120 or more after restoration of satisfactory arterial tension by adequate resuscitation.
2. Continued cyanosis after recovery from shock.
3. Dyspnea out of all proportion to the evident pulmonary pathology. In several patients with cardiac wounds in this series, oxygen had been necessary in the clearing station because of severe dyspnea and cyanosis.
4. The necessity for the early and continuous use of oxygen. These clinical findings were, of course, in addition to:

a. The obvious presence of a precordial wound.

b. The projection of the course of a missile which might reasonably have involved the heart.

In a number of instances, irregularities of cardiac rhythm were not apparent; abnormal cardiac sounds were not heard; and there was a notable absence of significant symptoms and signs, or those present were so trivial as to be misleading. Makins (*1*) had called attention to these observations in his account of cardiac injuries in World War I. Generally speaking, the safest plan was to suspect cardiac injury whenever a patient seemed generally washed out; had a sustained, rapid pulse with transient irregularities of rhythm; and had a persisting need for oxygen.

Adjunct Diagnostic Measures

Roentgenologic and fluoroscopic studies.—In 15 cases, there was roentgenologic evidence of the injury. In eight cases the films showed a foreign body in the region of the heart, and in four instances the object was termed fuzzy or double-contoured. In five cases the cardiac shadow was altered in size or shape. In two cases the object was thought to be in the region of the heart, but there was no definite proof. In localizing missiles within the cardiac shadow, it was necessary to use heavy penetration (fig. 13), accomplished by the bone technique or the use of the Potter-Bucky diaphragm. A missile could be completely overlooked if the chest was examined with the usual exposure. The interpretation of roentgenologic enlargement of the heart was also open to some question when roentgenograms were made shortly after injury, since there is usually no appreciable stretching of the pericardium when fluid first appears in it.

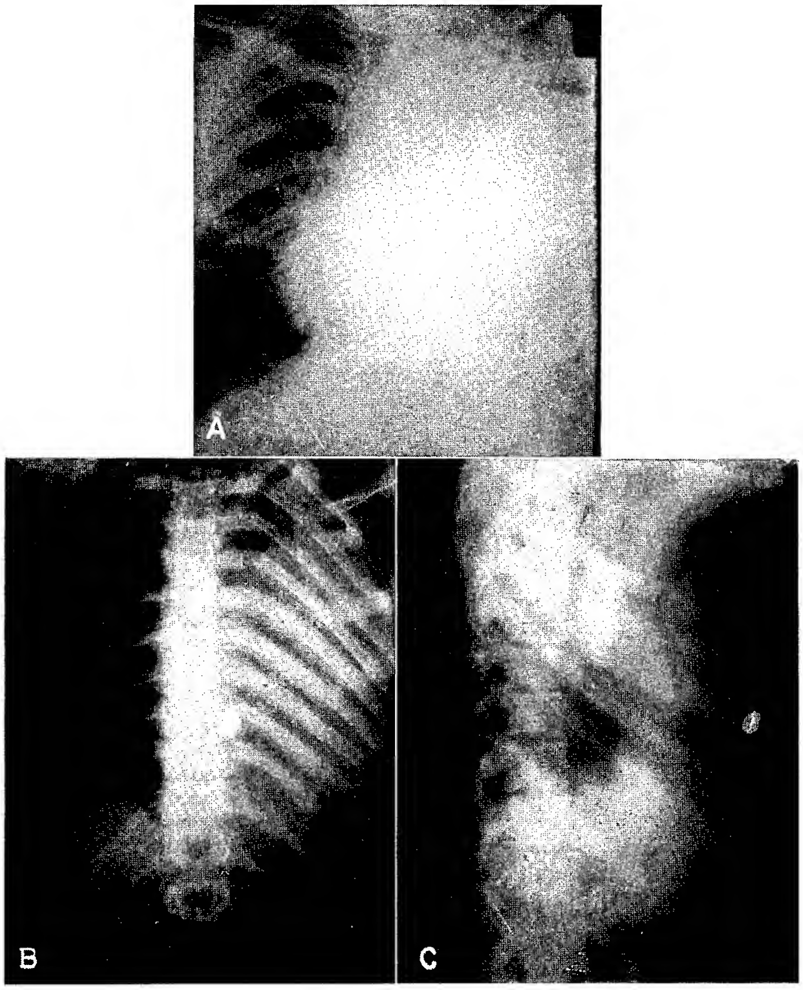

FIGURE 13.—Foreign body in left ventricle of heart. A. Posteroanterior roentgenogram, with massive left-sided hemothorax obscuring foreign body. B. Same, taken with deep penetration technique, showing foreign body in situ. C. Lateral roentgenogram.

Some cardiac injuries were not suspected until repeated X-ray studies in a general hospital, combined with fluoroscopy, revealed their presence.

The cardiac injury also might be suspected by plotting the probable course of the missile, using the external wounds and fractured ribs as landmarks. Diagnosis was accomplished, or suspicion was aroused, by use of this technique in 22 of the 75 cases in this series. On the other hand, it was easy to be misled concerning a cardiac wound if the foreign body happened to lie free in the pleural cavity.

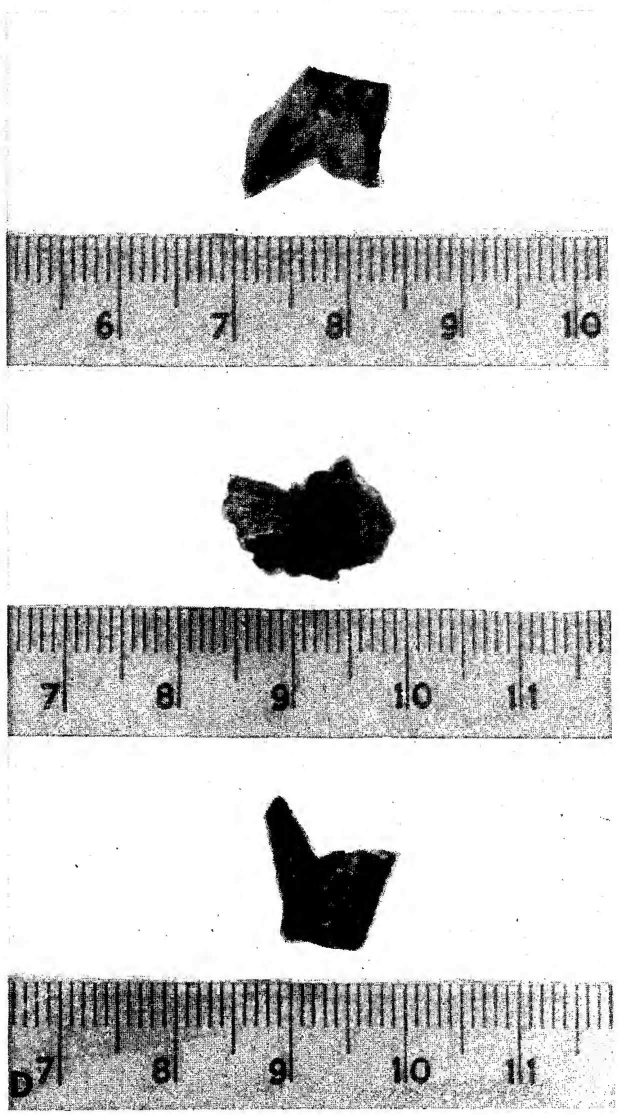

FIGURE 13.—Continued. D. Fragment after removal.

The diagnostic results might have been better if fluoroscopy had been employed more frequently, since this method permitted observation of possible movement of the object and also made it possible to determine whether it was included in the cardiac shadow in all projections. The cardiac outline was variously described as fuzzy, blurred, enlarged, or of water-bottle shape. In two cases in which the outline was described as blurred or fuzzy, operation revealed hemorrhage within the pericardial membrane and in the areolar tissues of the lower mediastinum.

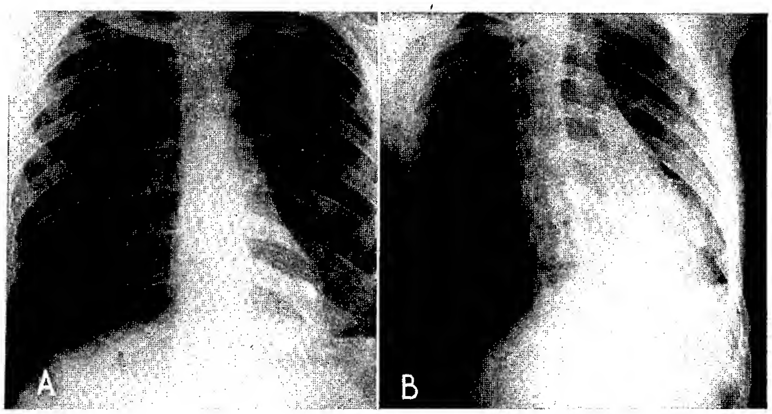

FIGURE 14.—Foreign body in wall of left ventricle near cardiac apex. A. Posteroanterior roentgenogram. B. Right anterior oblique roentgenogram. The electrocardiogram was consistent with myocardial injury.

Electrocardiography.—Neither electrocardiograms nor orthodiagrams were available in forward hospitals. Electrocardiograms were most helpful in determining whether a penetrating wound of the chest had involved the heart (fig. 14), particularly when the thorax was not explored at all or was incompletely explored at debridement. In numerous instances, these studies provided assurance that the myocardium had not suffered injury. In a few cases, progressive alterations in originally normal tracings indicated the necessity for removal of retained foreign bodies.

The most striking abnormalities, as reported by Lt. Col. Edward F. Bland, MC, were observed in myocardial injuries and involved the T-waves and S–T intervals. The predominating pattern was the so-called anterior-apical type, with inversion of T_1, T_2, and T_4 (fig. 15). In the posterior basal type of injury, electrocardiograms were secured in only two cases; in both, there was inversion of T_2 and T_3. Electrocardiograms with inverted T-waves in all four leads were obtained in five patients. In one of these cases, roentgenograms showed foreign bodies in both the anterior and the posterior cardiac walls. There was no explanation in the other cases for the total T-wave type of inversion.

High-grade conduction defects were not observed in any instance. Two patients with abnormal W-shaped QRS complexes of low voltage and inverted QRS complexes in lead four were thought to have sustained cardiac contusions. In one case, a persistent P–R interval of borderline significance (0.2 second) may have been normal for this particular patient.

In some cases, in which there was roentgenologic proof of the presence of the foreign body in the heart (figs. 16 and 17), electrocardiograms were completely normal.

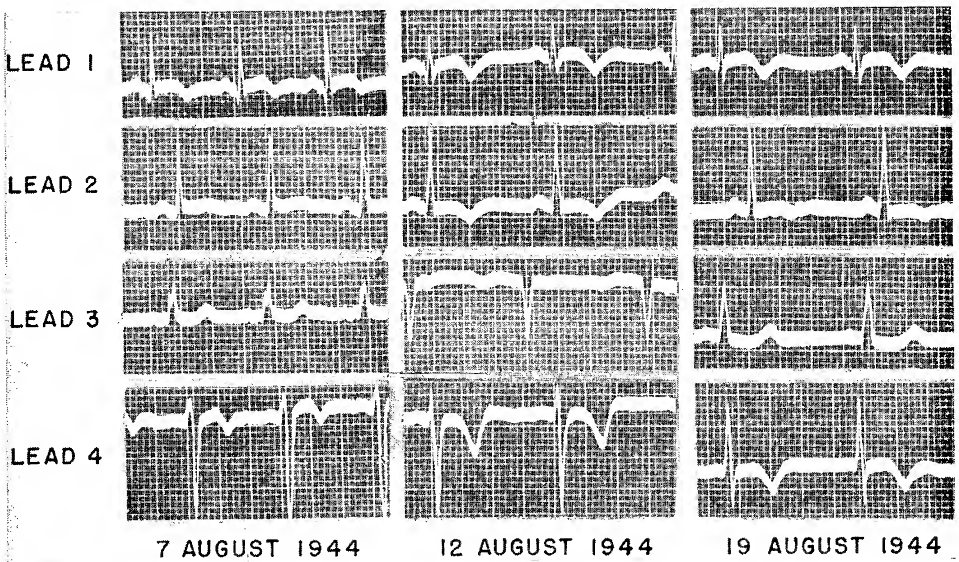

FIGURE 15.—Serial electrocardiograms taken after penetrating wound of heart. Note the anterior-apical pattern of T_1-, T_2-, and T_4-inversion encountered most often in cardiac wounds.

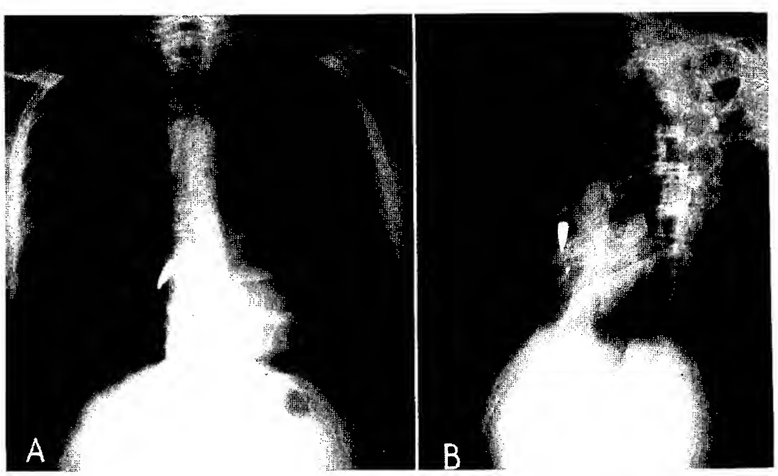

FIGURE 16.—Machinegun bullet in right side of heart near junction of right auricle and right ventricle. A. Posteroanterior roentgenogram. B. Left anterior oblique roentgenogram. The electrocardiogram showed no abnormalities.

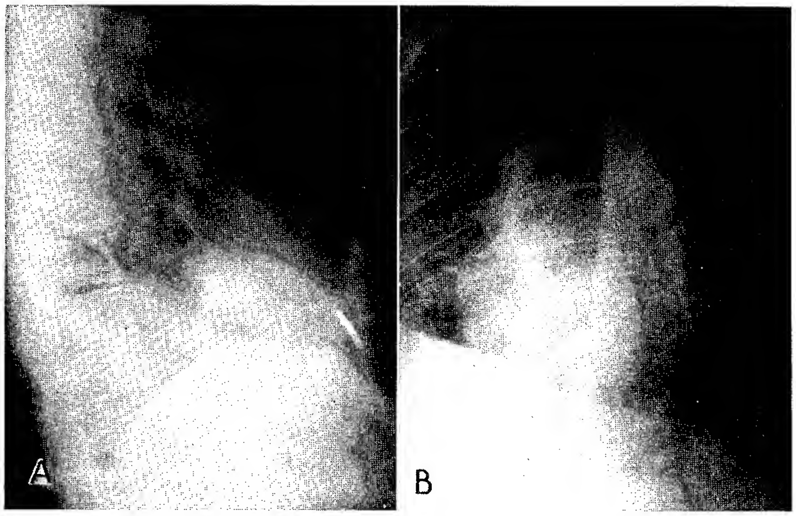

FIGURE 17.—Shell fragment in anterior wall of heart in region of right ventricle. A. Right lateral roentgenogram. The electrocardiogram showed no abnormalities. B. Right anterior oblique roentgenogram.

CARDIAC TAMPONADE

Hemorrhage into the restricted confines of the pericardial sac, with resulting cardiac tamponade, was the chief danger from a penetrating cardiac wound (fig. 18). Tamponade was, however, relatively infrequent in combat-incurred injuries, in contrast to its frequency in civilian cardiac injuries. The explanation is clear: In civilian life, small weapons, such as knives, icepicks, and small-caliber bullets, are generally used. As a result, the wound is small, bleeding is slow, and tamponade can develop as a physical possibility. In combat-incurred injuries, the wounds are large because the missiles are large, and an outlet for drainage into the pleural cavity is therefore provided. In a few cases, pneumopericardium occurred (fig. 19), without tamponade.

Hemorrhage into the pericardial sac was usually from the cardiac chambers but might also come from a severed branch of the coronary artery, from a pericardial vessel, or from the myocardium itself. The thick muscular wall of the ventricles seemed to tolerate severe lacerations, and even total penetration, without serious bleeding if the coronary arteries, especially arteries with sizable arterial branches, were not involved. In contrast, even slight tears of the thin-walled auricles were apt to be followed by tamponade, which could develop within the space of a few minutes and could be rapidly fatal if it was not promptly corrected. Most casualties in whom hemorrhage was sufficiently rapid to produce early tamponade probably did not live long enough to reach a hospital.

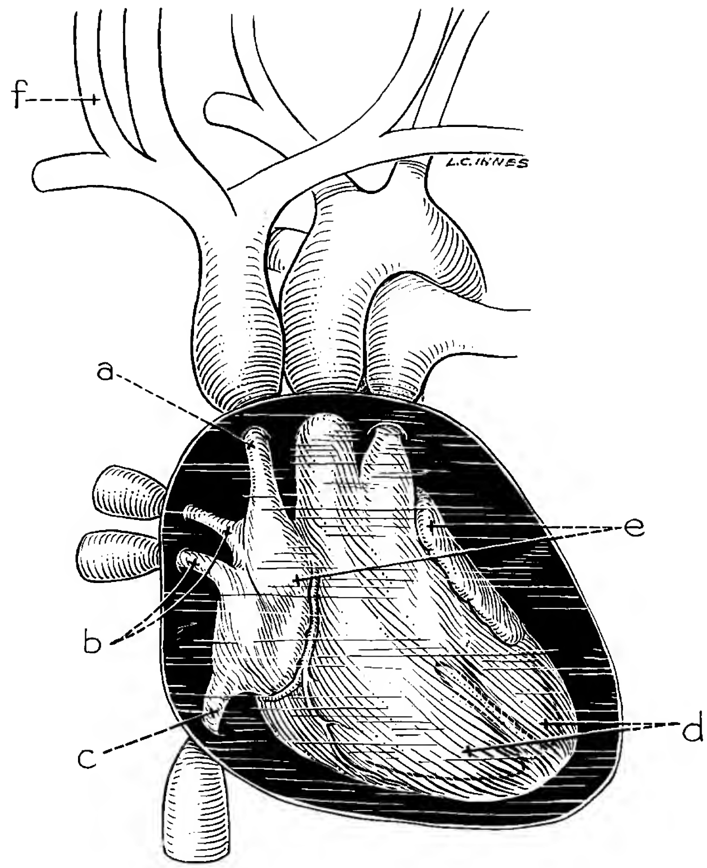

FIGURE 18.—Schematic showing of pathologic physiology of acute pericardial tamponade: Collapse of superior vena cava (a), collapse of pulmonary veins (b), collapse of inferior vena cava (c), impairment of diastolic filling of left and right ventricles (d), impairment of diastolic filling of stria (e), and increase of pressure in jugular vein (f). With these findings, the heart is silent and the pulse pressure decreased.

Diagnosis

The diagnosis of cardiac tamponade was generally based on the following findings:

1. *Lowered arterial pressure.*—In Elkin's (*3*) series, this finding was present in all cases, and in 17 of the 23, the blood pressure could not be recorded. In all the patients who recovered, the pressure rose immediately after release of the tamponade.

2. *Increased venous pressure readings.*—These readings, as Elkin (*3*) noted, are of both diagnostic and prognostic value. If the venous pressure is

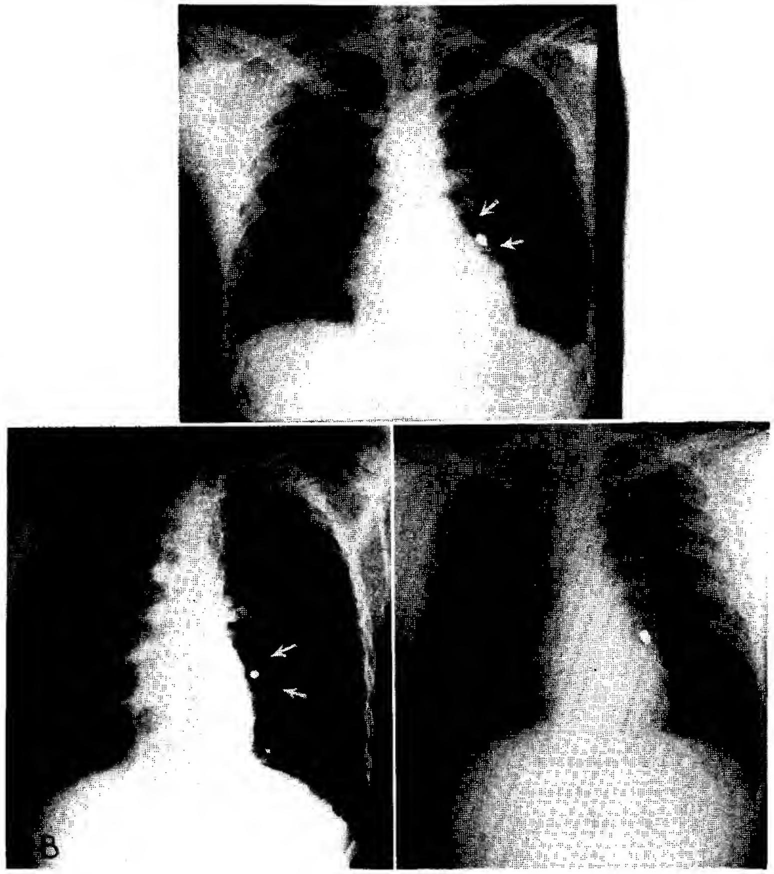

FIGURE 19.—Pneumopericardium with retained foreign body just behind heart. A. Posteroanterior roentgenogram, shortly after injury, showing massive pneumopericardium. B. Left (slight) anterior oblique roentgenogram showing retained foreign body. C. Posteroanterior roentgenogram 10 days later, after subsidence of pneumopericardium.

high, the assumption is that the cardiac output is at least sufficient to sustain life. If the venous pressure is low, or falling, the assumption is that the heart is failing and the cardiac output is correspondingly reduced. Three of Elkin's patients who presented this phenomenon died on the operating table or immediately after operation.

3. *A quiet heart.*—This finding was first described by Bigger (*4*) and, if it is studied fluoroscopically, the demonstration of decreased cardiac pulsations will be found to be extremely useful in diagnosis.

4. *Engorgement of the cervical veins.*—This phenomenon, which was present in a number of cases of tamponade, could readily be explained as the result of the inability of these veins to empty into the right auricle which was com-

pressed by the tamponade. When this finding was present, it was pathognomic, since such other causes as congestive heart failure, pulmonary embolism, and mediastinal emphysema were unlikely to be encountered under combat conditions. Absence of distended cervical veins, however, and even of a distended pericardial sac, did not necessarily exclude continued serious hemorrhage from a wounded myocardium. In one case in this series, in which there was continued, vigorous hemorrhage from a myocardial laceration, operation performed 10 hours after injury revealed that tamponade had been prevented by the passage of blood through the pericardial rent into the pleural cavity.

There were 5 instances of tamponade in the 57 cases in which the injuries involved the heart proper. Death occurred in two because the condition was not recognized or suspected. These cases and another case in which survival occurred have features of special interest:

Case Histories

Case 1.—This patient was injured in the left chest, shoulder, and buttock by shell fragments on 14 December 1944. He was not in evident shock and at a field hospital, his condition was listed as good. Breath sounds were diminished over the left chest. He was given 1,000 cc. of physiologic salt solution intravenously before operation, which was performed 7 hours after injury. All wounds were debrided. An open pneumothorax was closed without exploration. Aspiration of a hemothorax yielded 300 cc. of blood.

The patient's postoperative condition was good. The pulse was within normal range, the blood pressure was 90/60 mm. Hg, and there was full recovery from the anesthesia. Four hours later, he was turned in bed, at his own request. Shortly afterwards, he was found dead. Post mortem showed the pericardium to be distended with 200 cc. of blood and the heart to be constricted. A perforation of the superior portion of the pericardium on the left side, about 1.5 cm. in diameter, was occluded by a fibrinous exudate. A metallic fragment 1.5 by 1 by 1 cm. was found in the pericardial cavity. In the right ventricle was a laceration 1.5 by 1 cm. in length and 3 to 4 mm. in depth. A small branch of the right coronary artery was severed. Two small mural thrombi were found in the right ventricular cavity beneath the laceration. The liver was moderately congested. The cause of death was obviously cardiac tamponade, which had not been suspected before the post mortem examination.

Comment.—The operating surgeon, who witnessed the post mortem, expressed the opinion that this soldier's life could have been saved if (1) thoracotomy with control of the coronary bleeding had been carried out, or (2) if there had been closer postoperative observation for signs of developing tamponade, which could have been relieved by aspiration (fig. 20). It is possible that if tamponade had been relieved, hemorrhage might have ceased spontaneously. More likely, exposure and ligation of the severed artery would have been necessary.

Case 2.—This patient was in poor condition when he was received in a field hospital after sustaining a bullet wound of the right lower quadrant of the abdomen. The neck veins were swollen and the heart sounds were barely audible. Although cardiac tamponade was suspected, no blood could be aspirated from the pericardium, and roentgenograms failed to disclose a foreign body in or near the heart. At operation, 15 hours after injury, a tear in the colon was sutured, and a gutter wound of the liver was drained. Left thoracotomy was then performed. The pericardium was distended with clotted blood. The heart was constricted, and its enfeebled action soon ceased, despite vigorous efforts at

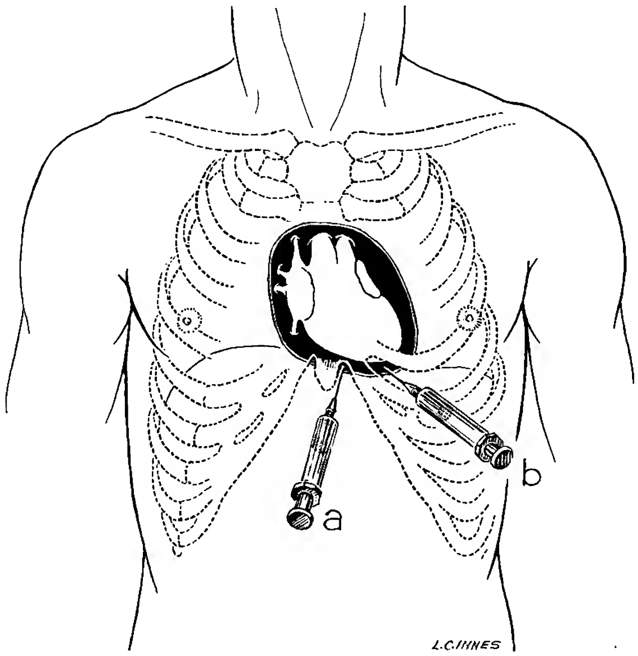

FIGURE 20.—Management of cardiac tamponade by aspiration: Substernal transdiaphragmatic aspiration (a), and left lateral aspiration (b).

resuscitation. Autopsy, which was performed immediately, revealed a .30-caliber bullet lying in the right ventricular cavity, surrounded by a foul-smelling clot. The bullet had been deflected upward from the pelvis and had passed through the colon and the liver before perforating the diaphragm and the right ventricular wall.

Comment.—A combination of unfortunate circumstances partly explained the fatal issue in this case. The negative results of two ordinarily reliable precautionary measures served to disarm suspicion. One was the pericardial tap, which was dry because the blood was clotted. The other was roentgenologic failure to demonstrate the missile within the thorax, probably because it was obscured by cardiac motion. Under these circumstances, the swollen cervical veins became extremely important from the diagnostic standpoint. They always indicated serious circulatory imbalance which demanded correction before other surgical procedures could be undertaken with safety. Whether or not this patient's life could have been saved by initial thoracotomy is debatable, but the fact that he survived 18 hours after wounding and withstood the added strain imposed by an extensive laparotomy before the chest was explored is highly suggestive. Had the operative procedures been reversed, it might have been possible to relieve tamponade, check myocardial hemorrhage, and perhaps remove the intraventricular bullet. Even if its removal had proved impossible, it might have migrated later to the pulmonary artery without necessarily serious consequences, as in another case in this series (case 9, p. 82).

Case 3.—This patient sustained a penetrating shell-fragment wound of the left lumbar region, with a fracture of the tenth rib, on 8 July 1944. He was received at the field hospital in moderate shock, with a blood pressure of 90/50 mm. Hg. At operation, 8 hours after injury, a segment of the ninth rib was resected, and 1,400 cc. of blood was evacuated from the pleural cavity. A hole in the pericardium 2.5 centimeters in diameter was extended to reveal a laceration of the same extent in the left ventricle, from which a small stream

of blood exuded with each heartbeat. The hemorrhage was controlled and the laceration closed by two figure-of-eight silk sutures in the ventricular wall. The pericardium was left open for a distance of 6 centimeters. The foreign body was found in the lower lobe of the left lung, with a hematoma but no hemorrhage. When the diaphragm was opened between the anterior and the posterior perforations, the spleen was found fractured and actively bleeding. It was removed. Two perforations of the stomach were sutured. The diaphragm and the chest wall were then closed.

The patient's immediate postoperative condition was good, the blood pressure being 110/70 mm. Hg. Ten days later, his condition was still good; he had no complaints, and temperature, pulse, and respiration were normal. There was no fluid in the pleura, but a pericardial friction rub was noted. The following day, the patient was transferred to a general hospital. On 23 July, he suddenly complained of severe dyspnea and precordial pain and became extremely cyanotic. The lungs were filled with rales. The pulse was 130. Gradual improvement occurred following the administration of morphine and oxygen, and 4 hours later, the lungs had cleared. The medical consultant made a diagnosis of acute left ventricular failure.

The following day, an electrocardiogram showed late inversion of T_1 and T_4, with low voltage of the QRS complexes, consistent with recent left ventricular injury and probably pericarditis. By 25 July, the patient was much improved; the heart sounds were good, and he had no cardiac symptoms. Electrocardiograms on 8 August and on 21 August were still abnormal, but the inversion of the T-waves was less marked. On 11 September, 8 weeks after injury, he was evacuated to the Zone of Interior in good condition.

Comment.—This case is of special interest on two counts: (1) In spite of serious injury to the heart, lungs, stomach, and spleen, this patient survived. His convalescence was undoubtedly hastened by early and adequate surgery. (2) This is the only case in the entire series of cardiac injuries in which delayed acute left ventricular failure occurred (on the 15th day). The precise explanation for this isolated and unexpected episode remains obscure. In this case, as in several others, cardiac tamponade was prevented by the escape of blood through a sizable pericardial rent. It is probable that the cardiac hemorrhage accounted for the major portion of the 1,400 cc. of blood evacuated from the left chest at operation.

PATHOLOGIC PROCESS

Cardiac injuries encountered at surgery or autopsy were classified as contusions, lacerations, lacerations and contusions, penetrating wounds of the cardiac chambers with retained foreign bodies, and perforating (through-and-through) wounds. Cardiac emboli were also possibilities. These injuries were additionally classified according to the particular cardiac structure involved.

Superficial abrasions of the epicardium and engorgement or thrombosis of the subepicardial vessels were often found. When a major artery was badly contused, thrombosis was a possibility.

The myocardium might show gross evidence of degeneration or actual necrosis. Microscopically, interstitial hemorrhage varied in variety and extent. The muscle fibers showed fragmentation, loss of striation, or advanced necrosis. Eosinophilia, leukocytic infiltration, and beginning phagocytic removal of necrotic muscle tissue were observed as early as 18 hours after injury.

When the endocardium was injured or there was subendocardial hemorrhage, adherent mural thrombi might develop. This was observed in five cases

in this series, in three instances at autopsy. When extensive lesions were scattered along the acute or the obtuse margins of the heart, the hemorrhage might involve the myocardium of both ventricles and extend into the interventricular septum.

The high rate of energy imparted to the tissues in the track of the missile explained why particles of tissue were thrown laterally and passed their energy on, thus producing further damage. Attention has already been called to the cases in which fragments of the ribs produced this sequence of events, which was especially likely to occur in tangential wounds.

In some instances, the missile passed through the myocardium at such an angle that the cardiac walls closed behind it.

PERICARDIAL INJURIES

General Considerations

There were 18 instances of pure pericardial injury in this series, with 3 deaths, all of which occurred more than 48 hours after wounding and none of which was due primarily to the pericardial injury. In 14 instances, the wounds were lacerated; and in 5, foreign bodies were present, in 2 instances consisting of rib fragments. One of these missiles was in the free sac.

In one case, injury of the pericardium was associated with an injury of the myocardium; it is quite remarkable that this combination of injuries did not occur more often, as some of the pericardial lacerations were severe. It is also quite possible that minor lacerations of the pericardium occurred and remained undetected. The academic question also arises as to the probable considerable margin of safety afforded by a heart in systole as compared with one in diastole at the moment of injury (Wood (*5*) and Nicholson's "near misses").

Management

The mere diagnosis of cardiac tamponade was not regarded as an absolute indication for surgical intervention. In several cases, prompt recovery followed pericardial aspiration alone (fig. 20), sometimes after a single aspiration. The general opinion, however, was that it was hazardous to depend routinely upon this type of conservative management, especially if an irregular foreign body with sharp margins or points was demonstrated in either the myocardium or pericardium. Under the circumstances, if more than two satisfactory aspirations were necessary, it was considered that surgery was indicated. The possibility of infection also had to be considered (p. 356).

In urgent cases, management consisted of repeated aspiration of the pericardium until surgery could be undertaken. The needle was inserted in the angle between the xiphoid process and the adjacent left costal arch and was directed cephalad, inward, and toward the left, at an angle of about 45°.

Repair was accomplished through a curved incision exposing the third, fourth, and fifth costal cartilages; resection of sufficient portions of these ribs to exposed the pericardium; incision of the pericardium; and suture of the wound by the technique recommended by Elkin (*3*) and by Beck (*6*).

In 5 of the 18 pericardial injuries, the pericardium was sutured tightly. In the remaining cases, drainage was instituted into the pleural cavity. In two of these five cases, in one of which there was an associated myocardial wound, there was massive, troublesome pericardial effusion postoperatively, a complication not observed in any case that was drained. Recovery in both cases followed paracentesis. All five foreign bodies were removed. In two other cases, in which it was thought that foreign bodies might be present in the pericardium, no attempt was made to remove them.

In one case, the pericardial sac was enormously distended with blood. It was incised for a distance of 10 cm. from the superior to the inferior margin, and there was no further bleeding after the first gush of blood. The pericardium was left open and the chest was closed. Recovery was uneventful. The origin of the tamponade in this instance was obscure, but the azygos vein, although it is usually extrapericardial and therefore an unusual source of intrapericardial hemorrhage, was considered the most probable source.

Pneumopericardium was observed in three of the pericardial injuries, as the result of the entrance of air into the pericardial sac from a pneumothorax, injured lung, bronchus, or esophagus. In two cases, the air was promptly absorbed, without evidence of pericardial irritation. In the other case, fibrous pericarditis developed.

While a pericardial wound was sometimes relatively innocuous, at least as compared to the lethal potentialities of other cardiac wounds, it could be extremely urgent. This is clear if the pathologic process (fig. 18) be considered: With fluid in the pericardium, an obstruction exists to the filling of the heart, and the blood is dammed up in the great venous channels of the body. If the intrapericardial pressure comes to equal the effective venous pressure, the blood can no longer enter the right auricle and death will occur promptly. That is why so many deaths from this cause must be assumed to have occurred on the battlefield and why, in some instances, the condition might be so urgent that the time required to confirm a suspected diagnosis by roentgenologic or fluoroscopic examination might mean the difference between life and death.

CONTUSIONS

General Considerations

The 16 contusions observed in the 2d Auxiliary Surgical Group series of cardiac wounds were similar to the contusions described by Elkin (*3*), Beck (*6*), and others in civilian life, as the result of blunt trauma to the chest, steering wheel injuries, and similar accidents.

There were 11 deaths in the 16 cases, in 6 of which the cardiac state was considered entirely responsible for the fatal outcome.

The diagnosis of a cardiac contusion was not particularly difficult. Most of the patients with significant injuries of this type presented signs and symptoms indicative of oxygen want and cardiac dysfunction, that is, tachycardia and arrhythmia. These signs and symptoms, as well as the gross and microscopic appearance of the myocardium at autopsy, had much in common with the clinical and pathological picture of myocardial infarction following coronary occlusion.

Pathogenesis and Pathologic Process

In most of the battle casualties, the damage resulted from the force propagated by the passage of a small, high-velocity missile in the immediate vicinity of the heart. In at least one instance of myocardial contusion (fig. 11), the ribs were shattered, and their fragments apparently acted as secondary missiles, with resultant direct blunt injury. Thrombus formation followed, and death ensued; the pericardium was intact.

Whether a localized blast effect resulted from the passage of the missiles in these cases cannot be answered. Certainly, in this series, no cardiac contusion resulted from the generalized effect of a pressure wave in the atmosphere. While it was theoretically possible for a serious cardiac injury to result from blast, there was no confirmation at autopsy, in which the possibility was borne in mind in the examination of patients who died of blast injuries.

Clinical and experimental studies before the war had clarified the pathologic physiology of thoracic contusions. Bright and Beck (*7*), as well as Warburg (*8*), had demonstrated that trauma to the intact chest, especially in the young adult whose chest is far more resilient and flexible than the chest of an older person, may be directly transmitted to the heart, whether the injury is a direct blow over the precordial region, compression of the chest between two solid objects, or a blow over the abdomen, with a sudden rise in intra-abdominal pressure.

Experimental trauma most often caused immediate rupture of one of the cardiac chambers, with death. Contusion, with resultant petechial hemorrhage, softening and necrosis of tissue, and eventual rupture, might involve any portion of the conduction system. Most frequently, it caused reflex spasm of the coronary vessels, with the production of a syndrome like the common civilian-type syndrome of coronary occlusion and infarction. It was also shown experimentally that in cases of vagosympathetic imbalance, or when the heart was sensitized by adrenalin, cardiac irregularities and coronary spasm resulted more readily. In the heat of battle, when the vascular system was surcharged with considerable adrenalin, slight trauma to the chest might conceivably cause considerable cardiac disturbance.

The pathologic process in contusive lesions consisted of scattered or confluent petechial hemorrhages involving the myocardium over various areas of one or both chambers (fig. 21). In these 16 cases, the ventricles were involved

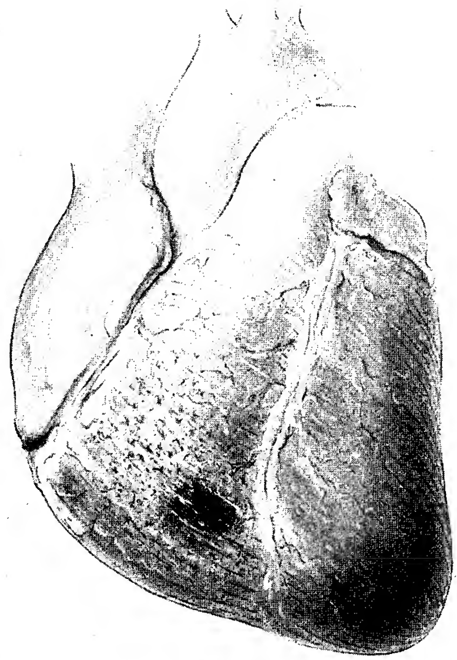

FIGURE 21.—Scattered petechial and confluent hemorrhages of right ventricle caused by the indirect force of a penetrating bullet wound of sternum.

15 times (7 left, 5 right, 3 both) and the right auricle, once. Superficial abrasions of the epicardium and engorgement of the subepicardial vessels were sometimes observed. The myocardial hemorrhage often extended through to the endocardium, and the muscles sometimes showed gross evidence of degenerative changes or actual necrosis. In fatal cases, in which there had been involvement of the entire thickness of the myocardium, mural thrombi were frequently found attached to the endocardium (fig. 11). When extensive lesions were scattered along either the acute or the obtuse cardiac margin, it was not uncommon to find hemorrhages extending into the myocardium of both ventricles, and even into part of the interventricular septum. The pericardium was not necessarily injured in myocardial contusion; it was intact in 9 of the 16 cases in this series. The pathologic pattern in the fatal cases was essentially one of subpericardial and subendocardial hemorrhage, usually petechial in distribution.

Management

A patient with a myocardial contusion was a poor risk for any kind of surgery, especially during the first several hours after wounding. The fact that 6 of the 11 deaths in these 16 cases were due to the cardiac lesion indicates just how poor risks these casualties were.

The contusion itself was not a surgical lesion, but, unfortunately, numerous associated wounds often required that surgery be done promptly. Ideally, it was postponed for 24 to 48 hours, but this was frequently impossible. Certain wounds, such as thoracoabdominal wounds, required prompt operation, in spite of the fact that immediately after injury, the risk of death from irritability of the myocardium and potentially lethal arrhythmias might be enhanced by anesthesia or surgical manipulations. The best that could be done was to delay surgery as long as possible, to permit some degree of cardiac recovery.

In the meantime, the patient was treated as if he were suffering from acute coronary occlusion. Resuscitation was carried out, and surgery was then undertaken with due realization that the risk was inevitably great and the mortality would be correspondingly high. In purely thoracic wounds, in which surgery was not mandatory within 6 to 12 hours, it was best to delay it as long as possible.

In three fatal cases in this series, in which operation was performed, respectively, at 5, 11, and 17 hours after wounding, it was thought that further delay might have been beneficial. Two of the wounds were purely thoracic. The other was a high thoracoabdominal wound, in which it was clear that only the liver was involved. In each instance, signs of cardiac dysfunction were prominent. During resuscitation, the patients were in poor general condition, semistuporous, with rapid pulse, and dyspneic out of all proportion to the visible intrathoracic damage. In each instance, the systolic pressure was elevated to 95 mm. Hg or higher, but death occurred on the operating table or immediately after surgery was concluded.

In another case of this kind, not included in this series, the timelag was only 6 hours. Death occurred on the operating table. At autopsy, it was confirmed that the wound was purely thoracic. There was extensive contusion of the right ventricle and thrombosis of the anterior descending branch of the left coronary artery.

Any of these patients might well have died, even if surgery had not been done, but the added burden of the anesthetic and the operative procedures cannot be ignored in assessing the outcome in seriously wounded patients.

In two other cases in this series, which may be cited in contrast, surgery was delayed for 3 and 5 days, respectively, after wounding. Both patients were received in shock. In one case, the pulse remained over 120 for 48 hours. In the other, for 4 days, there were intermittent periods of cardiac arrhythmia, associated with wet lung, pulmonary edema, and jaundice. In each instance, the surgeon expressed the opinion that the patient might well have died if operation had been done even as late as 12 hours after wounding.

The final conclusion was that if a cardiac contusion were diagnosed and such indications for early surgery as continuing hemorrhage or a thoracoabdominal wound did not exist, surgery should be deferred for at least 24 to 48 hours, to provide every opportunity for the reduction of myocardial irritability.

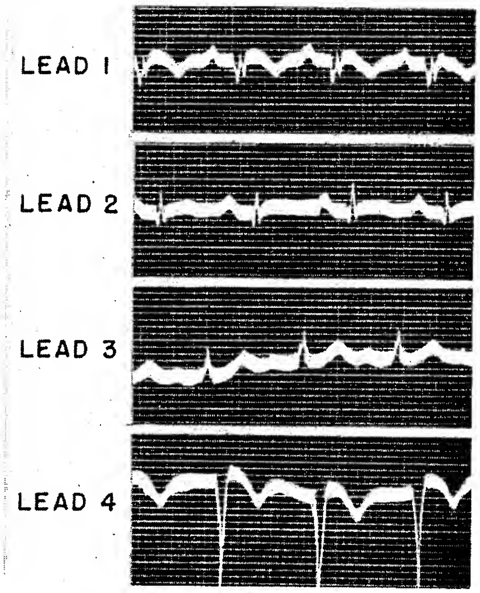

FIGURE 22.—Electrocardiogram of patient with cardiac contusion showing W-shaped QRS complexes of low voltage and inverted QRS–4. The same electrocardiographic phenomena were observed in another casualty with a cardiac contusion.

Electrocardiograms in two survivors of contused wounds were identical with respect to (1) abnormal W-shaped QRS complexes of low voltage in the limb leads and (2) inverted QRS–4 (fig. 22). This pattern was not observed in any other type of cardiac injury. These electrocardiograms also showed the abnormalities of T-waves and S–T intervals frequently seen after myocardial injury.

LACERATIONS

General Considerations

Of the 20 lacerations in this series, 10 were combined with contusions of the myocardium and 4 were detected only at post mortem. In the 10 pure lacerations, the left ventricle was affected in 7 cases, the right ventricle in 2, and the right auricle in 1. These 10 cases, in 2 of which there were foreign bodies in the myocardium, comprise all the instances in the series of incised, cleanly lacerated wounds of the myocardium in which there was no gross evidence of myocardial contusion or necrosis.

In the combined lacerations and contusions, the left ventricle was affected five times, the right ventricle twice, and both ventricles twice. In the remain-

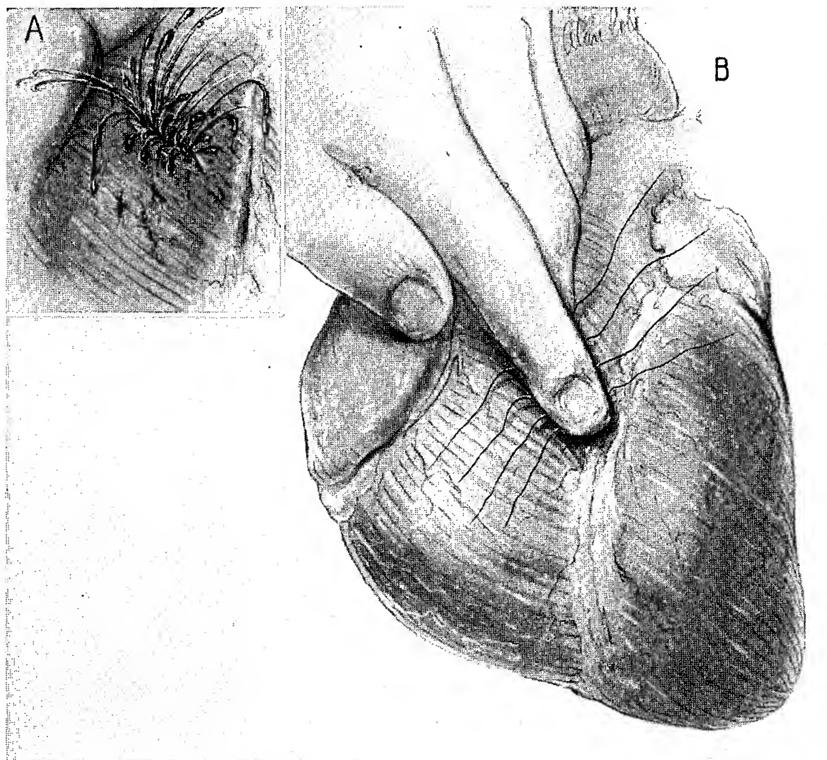

FIGURE 23.—Technique of cardiac surgery. A. Laceration of right ventricular wall without serious contusion. B. Direct suture of laceration of ventricular wall with digital control of bleeding.

ing case, the right auricle and right ventricle were injured. The serious implications of contusions are again evident in this group, in which there were five deaths, four due to the cardiac wound, against the single death due to a cardiac lesion in the pure lacerations.

Management

An analysis of the records shows that a rather surprising number—10—of the 16 lacerations of the myocardium were not repaired, and apparently with no immediate ill effects. In the four lacerations found only at post mortem, there was no evidence in any instance that the fatality was due to failure to effect a repair.

In the six cases which were repaired, the laceration was completely closed in four by suture. In the two other cases, complete approximation was impossible, and the pericardium was used to help bridge the defect; free muscle grafts were also used (figs. 23 and 24).

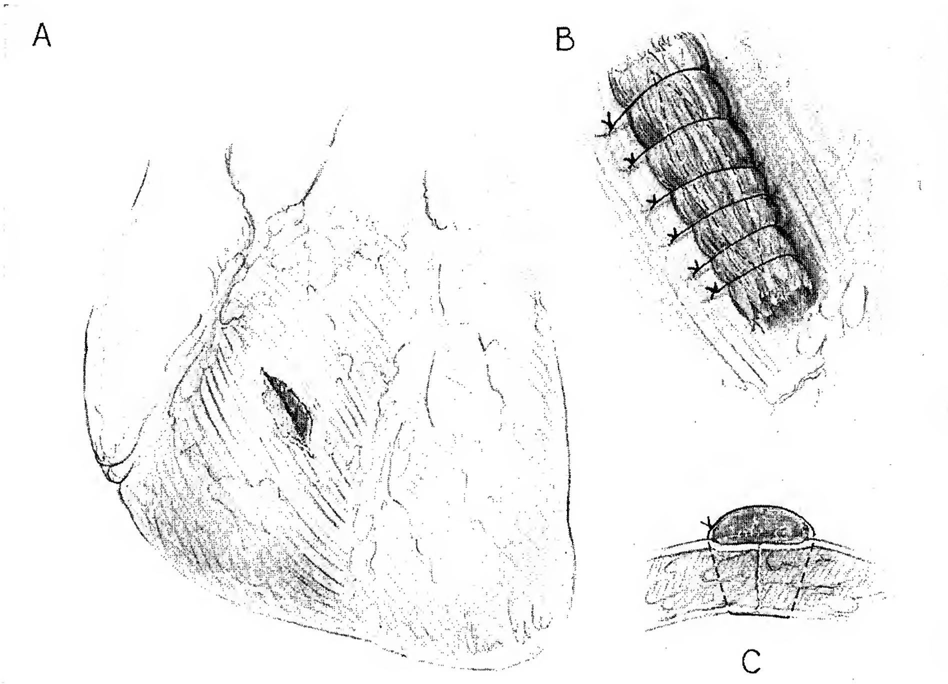

FIGURE 24.—Technique of cardiac surgery. Closure of penetrating wound of heart. A. Wound of right ventricle. B. Use of free muscle graft (greatly enlarged). C. Cross section of sutured muscle graft.

The pericardium was either sutured over the wound or sutured to the edges of the poorly approximated wound. In the former instance, posterior drainage was employed.

The number of cases is too small to permit drawing any conclusions as to the wisdom of operating in forward hospitals solely to suture cardiac lacerations.

PENETRATING AND PERFORATING WOUNDS

General Considerations

There were 19 instances of perforating or penetrating wounds of the heart in this series, 7 involving the left ventricle, 3 the right ventricle, 2 the left auricle, and 7 the right auricle. There were nine deaths, in eight instances due to the cardiac lesion. In one wound of the auricle, discovered only at post mortem, death occurred 24 hours after wounding. In the opinion of those who witnessed the autopsy, the fatal outcome was due to extensive wounds elsewhere in the body. It was thought that the patient would have survived without auricular repair. The most frequent complication, and the most important cause of death, was hemorrhage, which could readily be exsanguinating.

It is of great interest that through-and-through cardiac wounds were not always immediately fatal. In one case in this series (p. 75), recovery followed the repair of two wounds of the left ventricle caused by a shell fragment that divided the left phrenic nerve and the pericardiophrenic vessels, entered the left ventricle at the apex, and made its exit on the posterior wall. Operation was performed 14 hours after wounding.

One other patient with a through-and-through wound of the left ventricle also survived. The three perforations of the right auricle all ended fatally. In the experience of the 2d Auxiliary Surgical Group, no patient with a perforation of the interauricular or interventricular septum survived to reach a forward hospital.

Management

The chief indication for immediate surgery in wounds of the cardiac chambers was continuing hemorrhage. If bleeding caused tamponade rather than exsanguinating hemorrhage, as it sometimes did, treatment could be more individualized. If the tamponade developed rapidly, it was considered better to operate at once, particularly if it was known that the missile causing the wound was large. If the tamponade developed slowly, one or two aspirations might be attempted (p. 64).

If foreign bodies were encountered in the course of the operation, an attempt was made to remove them. If their presence was suspected, an attempt was made to locate them. If, however, they were not found immediately, the correct procedure was to control the hemorrhage and close the chest. Since hemorrhage was the indication for operation, a long-continued search for the missile, with blind manipulations within the cardiac chambers, could not be considered justified. The foreign body could be removed later at the base hospital if that proved necessary.

Complete closure of the cardiac wound was possible in 10 cases. One wound had ceased to bleed when it was exposed, and suture was not considered necessary. In two instances, both auricular wounds, attempts at closure failed, and both patients died of intractable hemorrhage. Attempts to plug the defect with the finger were unsuccessful.

Case Histories

Case 4.—This 22-year-old private was wounded by an artillery shell fragment on 27 June 1944. At the field hospital, 2 hours later, he was found to be mildly shocked, but he was conscious and in fairly good condition. Examination revealed a lacerated wound, 3 cm. long, in the fifth left intercostal space, just outside the midclavicular line. There was no dyspnea or hemoptysis. The heart tones were normal, and no adventitious sounds were heard. There were signs of fluid in the left pleural cavity. The abdomen was tender and resistant to pressure.

The patient became nauseated and vomited twice shortly after admission. A Levin tube was passed into the stomach, and 250 cc. of air and fluid were withdrawn; there was no blood in the gastric contents.

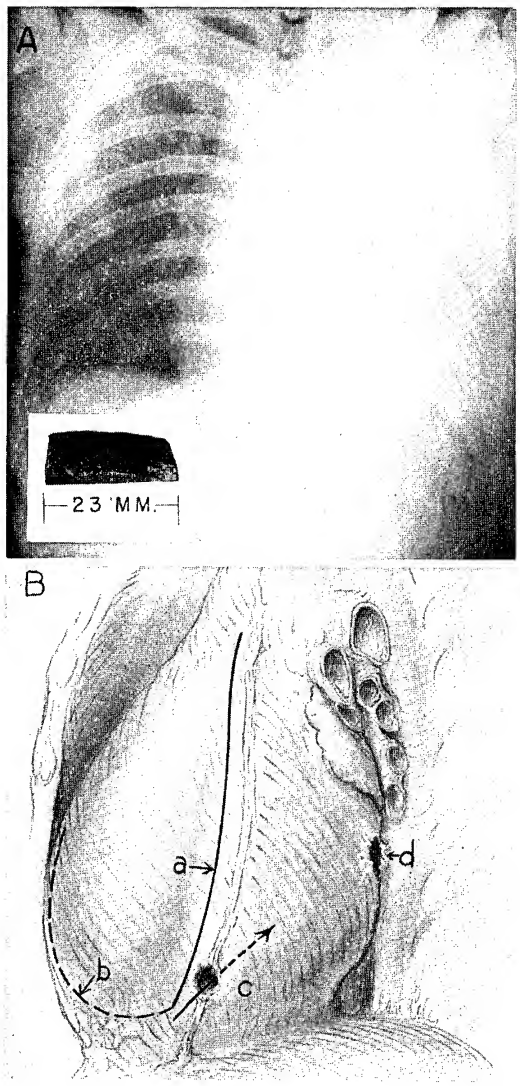

Figure 25 (case 4).—Repair of through-and-through wound of heart. A. Posteroanterior roentgenogram showing large left hemothorax, which obscures lung. Shell fragment at level of ninth rib posteriorly measured 23 by 10 by 4 mm. (insert). A Levin tube can be seen faintly at the level of the eleventh intercostal space on the left. B. Drawing depicting anterolateral laceration of pericardium with severance of pericardiophrenic artery and phrenic nerve, as follows: Incision for exposure (a), incision for flap (b), wound of entrance (c), and wound of exit (d). Note relation of wounds to important blood vessels.

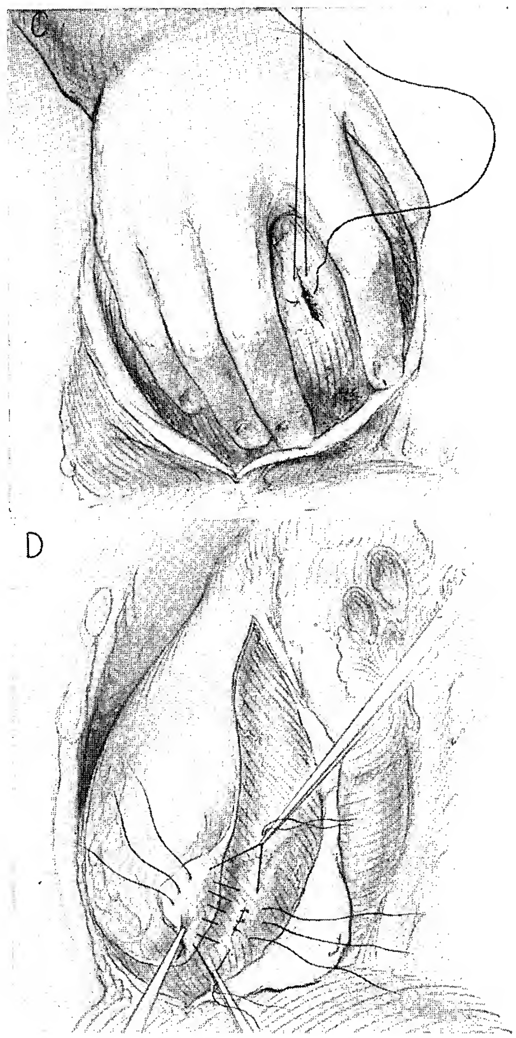

FIGURE 25.—Continued. C. Closure of anterior heart wound. Apex of heart held by right hand of assistant, exposing anterior laceration. D. Reinforcement of anterior cardiac wound by suture of pedicled graft of pericardium.

After 500 cc. of plasma and 1,000 cc. of blood had been given over a 2½-hour period, the blood pressure rose from 80/60 to 130/70 mm. Hg, and the pulse fell from 110 to 90. Abdominal signs and symptoms persisted. Roentgenologic examination (fig. 25A) showed the shell fragment lying well posterior, apparently just within the costal cage. From the location of the wound, the apparent course of the missile, and the persisting abdominal signs, especially the nausea and vomiting, a thoracoabdominal wound could not be ruled out.

Operation was carried out under endotracheal anesthesia 6 hours after wounding and 3½ hours after hospitalization. Blood transfusion was continued during the procedure.

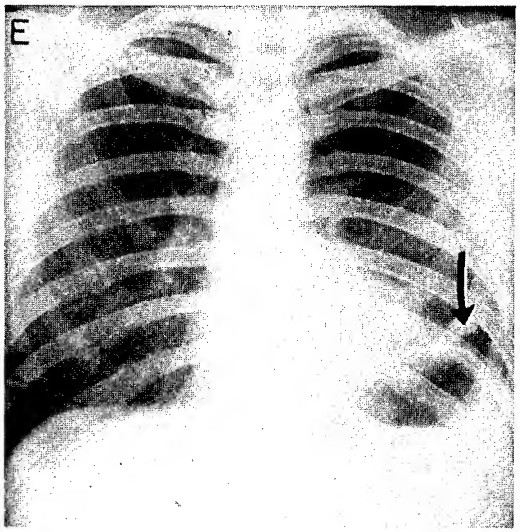

FIGURE 25.—Continued. E. Posteroanterior roentgenogram 8 weeks after operation, showing clear lung fields, no cardiac enlargement, and elevation and paralysis of left diaphragm. Note chip fracture of fifth rib anteriorly (arrow).

After debridement, anterior thoracotomy was performed in the fifth intercostal space by extension of the wound of entrance. A chip fracture of the fifth rib was found, with a small contusion of the lingula of the left upper lobe, but the diaphragm was intact. Five hundred cubic centimeters of blood were evacuated from the pleural cavity, after which the shell fragment was discovered lying free posteriorly. Two perforations were seen in the pericardium. The pericardiophrenic artery and phrenic nerve had been severed anterolaterally (fig. 25B), and a posterior laceration was found just lateral to the reflection of the parietal pleura from the pericardium onto the mediastinum. The pericardial sac was opened by vertical incision a few minutes after 5 cc. of procaine hydrochloride had been injected into it. Two lacerated wounds of the left ventricle, each 8 mm. in length, were found oozing blood with each systole. The wound of entrance was at the apex and the wound of exit in the midportion of the left ventricular wall posteriorly (fig. 25B).

The apex of the heart was rotated 90° forward and steadied by the right hand of the assistant (fig. 25C). The wound was exposed between the spread of his second and third fingers, and bleeding was controlled by the application of two silk sutures (No. 0). A small venous branch was occluded by the sutures.

The anterior laceration was irregular, and the muscle gaped slightly. Oozing continued, particularly after a suture had cut partly through the muscle. It was controlled by suturing a small pedicled graft of anterior pericardium and pericardial fat over the laceration (fig. 25D).

Extrasystoles were numerous while the heart was manipulated but ceased immediately when manipulations were discontinued. Crystalline sulfanilamide and penicillin were placed in the pleural cavity, and drainage was instituted by means of two water-trap tubes. A small mushroom catheter was used in the second intercostal space anteriorly

and a quarter-inch fenestrated tube in the eighth intercostal space in the midaxillary line. The tube was clamped off for 8 hours after operation, to permit contact of the chemotherapeutic agents with the tissues. The incision was closed in layers, without pericostal sutures.

At the conclusion of the operation, the blood pressure was 110/70 mm. Hg. the pulse 145, and the respiration 32. Standard postoperative measures were employed. Recovery was generally smooth. The blood pressure remained normal; the pulse stabilized at 100–110. Cardiac irregularities were never evident.

Twenty-four hours after operation, a splash, synchronous with systole, was heard over the precordium. Four days later, a loud precordial friction rub was audible for 24 hours; during the same time, the second sound in the pulmonic area was occasionally reduplicated. On the sixth day, there was a slight roughening of the first sound at the apex, and a poorly transmitted, soft systolic murmur was heard in this area.

When the patient was transferred to a general hospital on the 12th postoperative day, he was afebrile, with a pulse of 88 and a blood pressure of 115/60 mm. Hg. He became ambulatory in another week. A scratching to-and-fro precordial friction rub was heard intermittently for another 2 weeks.

Roentgenologic examination 8 weeks after operation showed the lung fields clear and the heart normal in size (fig. 25E). Electrocardiograms 2 weeks after operation showed moderate inversion of T-waves with elevated S–T intervals in the first three leads and moderate left axis deviation (fig. 26). Two weeks later there was less inversion of T_1. Another electrocardiogram 2 weeks after the first showed T_1 upright, but T_2 and T_3 remained deeply inverted, and left axis deviation persisted.

No signs of cardiac embarrassment developed as the patient increased his activities, and he was in excellent condition when he was evacuated to the Zone of Interior 11 weeks after injury.

Comment.—This case is remarkable because, in spite of the through-and-through wound of the heart, the patient survived, after early, adequate surgery. Convalescence was quite smooth. It is noteworthy that in spite of the double wound in the ventricle, the blood loss was minimal. It is also noteworthy that no signs of cardiac weakness ensued in spite of the multiple wounds elsewhere, plus the necessary manipulation of the heart at operation and the repeated intravenous infusions of blood and saline solution that were necessary.

The serial electrocardiograms available in this case were thought to be the first on record taken during recovery from a complete perforation of the heart. It is of some interest that the effect of the T-waves in leads II and III of the posterior (basal) injury appears to have overshadowed the effect of the apical wounds (leads I and II), possibly because of the greater mass of muscle injured in the penetration of the thicker basal wall of the ventricle.

That this patient survived his original wound seems due to a happy and unusual chain of circumstances. The fragment must have struck end-on and passed through the heart without revolving. It also seems probable that the perforation occurred during diastole, so that the chamber was traversed by the missile without irreparable damage to the papillary muscle.

As this case also demonstrates, there may be few if any localizing signs or symptoms in spite of a serious cardiac wound. The nausea and vomiting were probably cardiac in origin; these symptoms do not usually occur in pure thoracic injuries. With the shell fragment free in the pleural cavity, the course of the missile was misleading, and the wrong conclusions concerning it were drawn. Had the missile come directly from the front, it could not have failed to penetrate the diaphragm. It came, however, from the left, passed through the heart, and then fell free in the pleural cavity, almost opposite the wound of entrance in an anteroposterior plane.

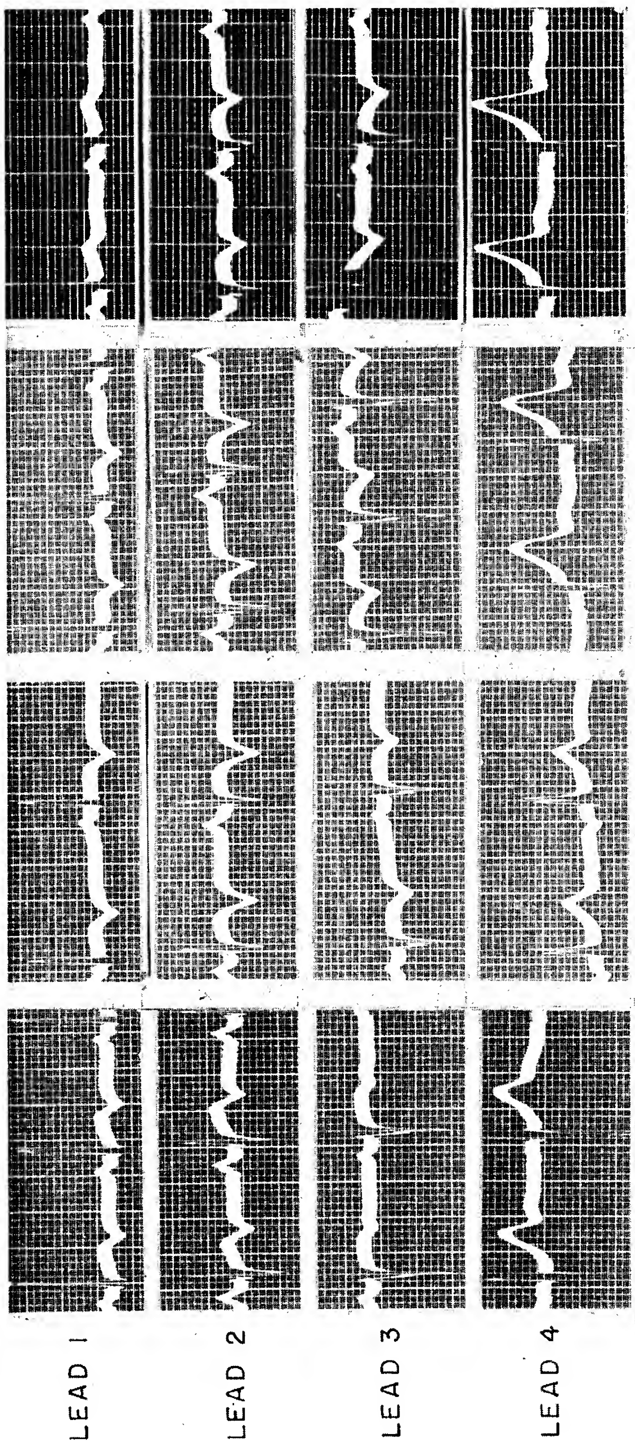

FIGURE 26 (case 4).—Repair of through-and-through wound of heart. Serial electrocardiograms 12 days, 17 days, 41 days, and 56 days after wounding. Note that residual inversion of T_2 and T_3 overshadows the temporary inversion of T_1 (T_2) pattern of anterior-apical injury.

Case 5.—In another ventricular injury, the patient died in the shock ward of a field hospital 6 hours after he had received a penetrating wound of the left chest, before operation could be performed. Autopsy revealed that a single shell fragment, 1 by 1 by 1 cm., had entered the chest through the left scapula, fractured the third and fourth ribs posteriorly, and then perforated the wall of the left ventricle, to become embedded in the opposite ventricular wall. Death was caused by hemorrhage from the heart into the left chest. The rent in the pericardium had permitted the escape of blood and thus prevented tamponade.

Comment.—The comment of the medical officer who performed the autopsy was that this man had lived for 6 hours with a hole in his heart and that his life might have been saved if adequate blood had been available and if the chest had been opened at once.

MIGRATORY FOREIGN BODIES

General Considerations

The intravascular migration of projectiles and other foreign bodies to the heart and pulmonary circulation from distant wounds by way of the great veins is so uncommon as to constitute a true medical curiosity.[1] Although still rare, these migratory objects were recognized more frequently in World War II than in the past. The need for their removal was still the subject of some disagreement. Some objects remained asymptomatic for long periods of time, but others, because they served as foci of infection or caused damage to the myocardium, caused death from embolism. Early removal in a base section center was considered the wisest plan if cardiac disability or other clinical signs and symptoms were present. Otherwise, the policy was to return the patients to the Zone of Interior.

If the fragment entered the pulmonary circulation from the right heart, it was theoretically possible for it to serve immediately as a fatal embolus. Removal of a missile from the pulmonary vessels could be attended with great difficulty and might require the sacrifice of an essential artery, perhaps with lobectomy or pneumonectomy. In one case in the 2d Auxiliary Surgical Group experience, surgery was not carried out for this reason (case 9, p. 82).

Migratory foreign bodies were not necessarily fatal. Three of five patients observed in the Mediterranean theater are known to have recovered, and at least one of the two deaths was not caused by the presence of the foreign body, while the same comment is possibly applicable to the other case. The case histories follow.

Case Histories

Case 6.—A soldier who sustained a penetrating shell-fragment wound of the right cervical region on 17 June 1944 was treated conservatively. Roentgenograms revealed a

[1] Although only one instance of migratory foreign body seems to have been reported in World War I (*9*), undoubtedly others occurred. In the reported case, a shell fragment buried in the liver was left in situ at operation. The patient died of peritonitis 6 days later. At necropsy, the metal fragment was found covered with fibrin and enmeshed in the columnae carneae. Examination of the liver disclosed the track of the fragment into its point of entry into a large hepatic vein and its subsequent intravascular passage to the heart.

foreign body in the right mid lung field, with no evidence of pulmonary injury. He was discharged to duty on 21 July but on 9 August was readmitted to the hospital, complaining of dyspnea and a vague pain in the right chest on effort. Rœntgenograms showed the foreign body in the same position as at the first examination. At exploratory thoracotomy on 18 August, the missile was found in the right inferior branch of the pulmonary artery. It was palpated through the wall of the artery but was not removed. On 10 October, when the patient was evacuated to the Zone of Interior, he was ambulatory but was still mildly dyspneic, and he continued to complain of vague chest pains on effort.

Comment.—When this patient was first admitted to the hospital, it was thought that the missile had entered the thorax directly from the cervical wound. In the light of the findings at operation, however, it must be assumed that it penetrated the right subclavian vein, migrated to the right side of the heart, and thence passed to the right pulmonary artery. No infarction resulted, and it was considered unlikely that it would cause serious trouble at its present site.[2]

Case 7.—This man sustained penetrating wounds of the right flank on 11 October 1944, with a resulting perforation of the colon and another of the left chest, with hemothorax.

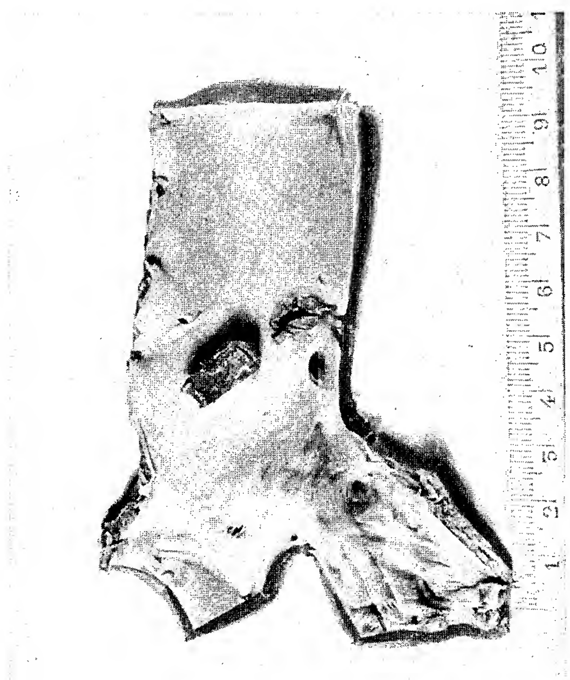

FIGURE 27 (case 7).—Migratory intravascular foreign body. Lower portion of inferior vena cava showing wound of entry and superimposed metal fragment that had passed as embolus to branch of left pulmonary artery.

[2] As already pointed out (p. 17 fn), postwar experimental studies by Dr. Lyman A. Brewer III and his associates showed that metallic foreign bodies in the lobar branches of the pulmonary artery are usually well tolerated, provided that the bronchial arteries remain intact. Those occluding the main pulmonary arteries cause serious pulmonary changes and should be removed.

The following day, laparotomy and colostomy were performed, and the chest wound was closed. On 25 October, he died from an intraperitoneal hemorrhage. Necropsy revealed multiple penetrating wounds, including a puncture wound, 0.8 cm. in diameter and surrounded by necrotic tissue, on the posterior wall of the inferior vena cava just above its formation. An embolic shell fragment 1.5 by 0.6 by 0.4 cm. was found in the inferior branch of the left pulmonary artery, with no evidence that it had entered through the lung parenchyma (fig. 27). There was no associated pulmonary infarction. The anatomic cause of death was massive hemorrhage secondary to the abdominal wound.

Comment.—The metallic embolus to the lung found in this case at autopsy was a complete surprise. There had been no signs or symptoms suggestive of its presence before death, and roentgenologic study had not seemed justified because of the patient's continued precarious state. It is entirely probable that he would have recovered from the vascular injury had he not succumbed, 2 weeks after wounding, to the secondary complications of his severe abdominal injuries.

Case 8.—This patient sustained penetrating wounds of the right shoulder and the right lumbar region on 2 October 1944. Though laparotomy revealed that a foreign body had entered the abdomen, it could not be found. Subsequent roentgenograms suggested that it was on the right side and lying in the psoas muscle. On 7 October, the roentgenograms were repeated because the patient had continued to run fever and had developed rales on the left side. The film was hazy, and the foreign body seen in the first film on the right side now appeared to be above the diaphragm on the left side.

Two days later, the temperature rose to 104° F. Other findings included a rapid pulse (from 140 to 160); a blood pressure of 95/50 mm. Hg; a variable systolic sound of unusual character over the heart to the left of the lower sternum, somewhat suggestive of a friction rub; and pulmonary rales. There was no venous distention. Roentgenograms revealed the foreign body apparently lying anteriorly and inferiorly in the pericardium and slightly blurred by motion. On 12 October, the patient continued to have fever, pulmonary rales were still present, and the superficial systolic "noise" persisted. His condition deteriorated progressively, and he died before a definite diagnosis was made, though the pyrexia was thought to be due to malaria.

At autopsy, when a penetrating wound in the right flank was explored, a track was found which indicated that the foreign body had entered the inferior vena cava. Continued exploration revealed it lying free in the right ventricle (fig. 28A). The entrance of the missile into the inferior vena cava was represented by an oval defect 1.5 by 1.5 by 5 cm. in the posterior wall above the bifurcation (fig. 28B). The defect was surrounded by numerous thrombi, some of which appeared to have become detached. The fragment found in the right ventricle near the apex was large and irregularly oblong. It measured 2.3 by 1 cm. and weighed 10.35 grams. There was slight discoloration of the adjacent endocardium, but no thrombi were found. Careful examination of the heart and vena cava revealed no evidence of penetration, and there was no doubt that the metal fragment had entered the vascular system through the wound in the lower vena cava. Both lungs showed widespread areas of infarction, and multiple emboli were demonstrable in the pulmonary arterial branches. In addition, there was massive intraperitoneal hemorrhage (1,500 cc.) from an omental vessel.

Comment.—In spite of the size and weight of this jagged fragment, it had apparently churned about in the right ventricle for over a week without causing serious injury to the cardiac wall. Although it was apparently too large to pass through the pulmonary orifice, at no time did the patient exhibit acute seizures suggesting a ball-valve effect, and at no time were the cervical veins distended. The persistent fever and downhill course were adequately explained by the recurrent pulmonary emboli from the mural thrombi in the lower vena cava, but these phenomena were probably unrelated to the presence of the foreign body in the right ventricular cavity.

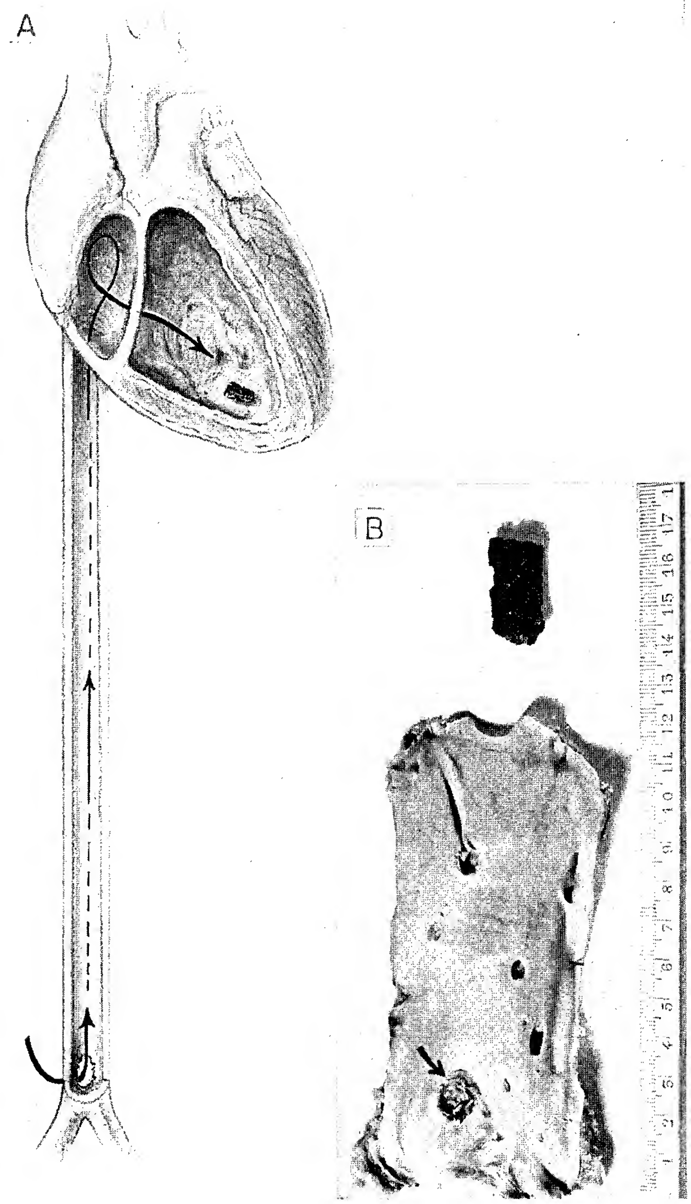

FIGURE 28 (case 8).—Migratory intravascular foreign body. A. Large oblong shell fragment free in chamber of right ventricle. B. Lower portion of inferior vena cava showing wound of entry surrounded by thrombi just above bifurcation. Fragment in ventricle is shown above.

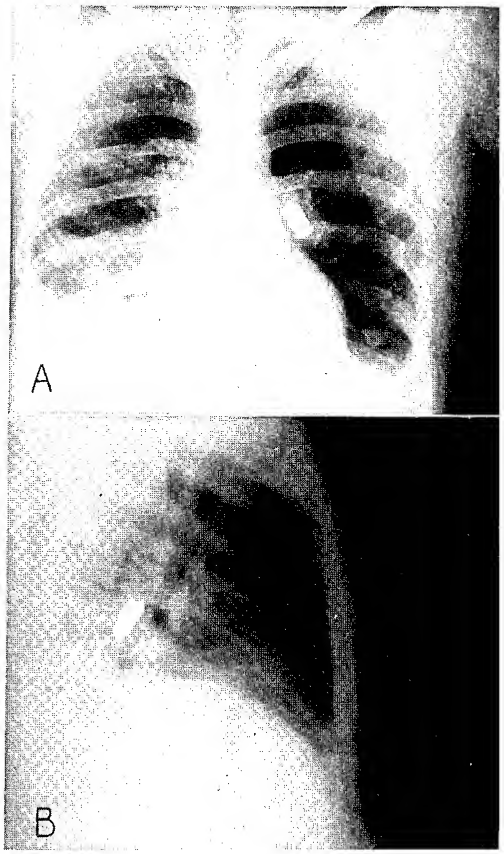

FIGURE 29 (case 9).—Migratory intravascular foreign body. A. Posteroanterior roentgenogram showing shell fragment in left hilar region. B. Left lateral roentgenogram localizing foreign body to intrahilar pulmonary area. The foreign body could not be found in this position or elsewhere at operation.

Case 9.—When this soldier was wounded in action on 12 April 1944, he sustained multiple severe penetrating wounds of the right thorax, right leg, and both feet. Initial roentgenologic study showed a large metallic foreign body in the left lung. The wounds were debrided.

On 28 April, when he was transferred to a thoracic surgery center, his condition was good except for moderate dyspnea, which continued after cardiorespiratory disequilibrium had been treated by adequate thoracentesis and nerve block. Localization studies showed the fragment to be in the hilar region of the left lung (fig. 29A and 29B). Fluoroscopy on 9 May showed it to be in the root area on this side.

At thoracotomy the following day, the foreign body could not be found, and the chest was finally closed after a long and fruitless search for it. Roentgenograms taken immediately after operation revealed it lying in the right hilar region (fig. 29C).

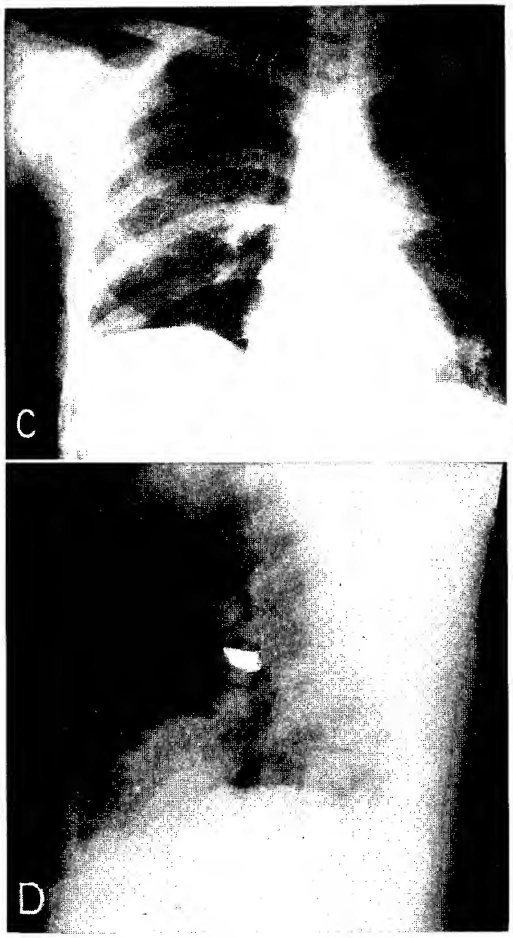

FIGURE 29.—Continued. C. Posteroanterior rœntgenogram immediately after left thoracotomy showing foreign body in right hilar region. D. Right lateral roentgenogram showing fragment again localized in root area of lung. At operation immediately afterward, it was found in the lumen of the main right pulmonary artery, where it was left in situ.

After operation, the patient remained more dyspneic than seemed warranted by the findings in the chest. The only change noted on electrocardiography was a moderate sinus tachycardia.

On 9 July, a right-sided thoracotomy was done, after repeated roentgenograms and fluoroscopy immediately before operation had shown the fragment still in the right hilar region (fig. 29D). The missile was found impacted within the lumen of the main right pulmonary artery. A palpable thrill was felt over it and for a short distance into the artery distally. The pulmonary circulation was entirely adequate. Complete dissection of the hilar structures did not achieve sufficient mobilization of the artery to warrant an

attempt to remove the missile, since the involved segment of the artery lay directly beneath the superior pulmonary vein anteriorly and upon the right stem bronchus posteriorly. Since there was no evidence of aneurysmal dilatation of the artery or of inadequacy of the pulmonary circulation, it was decided not to sacrifice the posterior pulmonary vein in order to remove the foreign body.

Convalescence was uneventful except for a disproportionate degree of dyspnea for a few days following operation. The patient was transferred to the Zone of Interior on 16 August, ambulant and in good condition. In October, a followup letter from the United States reported that he had continued well, with no symptoms other than dyspnea when he walked rapidly. No further roentgenologic studies and no operative procedure had been carried out.

Comment.—This case might be fairly termed unique in medical annals. The opportunity for adequate roentgenologic study and for complete exploration of both hilar regions by a competent chest surgeon left no doubt that the large metal fragment had migrated, against the blood flow in the pulmonary circuit, from its original position in the left pulmonary artery to its subsequent lodgment in the right pulmonary artery, without causing serious symptoms or recognizable complications. The exact mechanism of the migration is difficult to explain. It seems unlikely that it was accomplished by gravity alone. It may have been the result of manipulation during the exploration of the left hilar region, but no definite statement can be made on this point.

It is a matter of special interest that during a review of this case shortly after the first thoracotomy, the operating surgeon stated that the missile had probably entered a major lobar radicle of the right pulmonary artery and had progressed from there.[3]

Case 10.—This patient sustained a machinegun bullet wound which penetrated the right chest, just below the middle third of the clavicle, on 31 May 1944. On 4 June, he was transferred from a field hospital to a general hospital. He was then in fair condition except that his temperature was 102° F., the heart sounds were distant, and the veins of the neck were distended. Roentgenograms showed an enlargement of the heart shadow and a foreign body 1.7 by 1 cm. inside the left cardiac border. In the right chest was a moderate collection of fluid. On 7 June 1944, there was considerably increased distention of the neck veins, and the venous pressure was 210 mm. H_2O. Electrocardiograms showed QRS complexes of low voltage. Pericardicentesis produced 750 cc. of old, bloody fluid. The patient showed prompt improvement but had a pericardial friction rub for the next 3 days. Roentgenograms showed a smaller heart shadow, together with a surprising shift of the foreign body, which now lay just inside the right border of the heart. By 20 June, the patient was ambulatory. His improvement was progressive and satisfactory except that he complained of a dull pain running from the sternum to the cardiac apex when he walked. Roentgenograms showed the foreign body now lying behind the cardiac apex just inside the left border. On 2 August, the foreign body, which was embedded in dense pericardial adhesions behind the apex, was removed, with considerable difficulty. On 2 October, the patient was evacuated to the Zone of Interior fully ambulatory and complaining only of slight substernal ache on effort.

STAB WOUNDS

The single stab wound in the series, which was self-inflicted, was similar to the same type of injury observed in civilian practice. Emergency surgery, 16 hours after injury, was required to control hemorrhage from a small punc-

[3] This patient was seen again in 1948, at which time he was perfectly well. In April 1959, he suffered profuse hemoptysis because the foreign body had eroded through the right pulmonary artery into the right bronchus intermedius. Pneumonectomy was necessary, from which he made a good recovery. He has remained in good health to date (October 1960).

ture wound of the left ventricle near the left descending coronary artery. A laceration of the myocardium was also sutured. The postoperative electrocardiograms showed inversion of T_1, T_2, and T_4. The patient was evacuated to the Zone of Interior in good condition 8 weeks after operation.

INJURIES OF THE GREAT VESSELS

Since lacerations and penetrations of the great vessels were apt to be quickly fatal, it is not surprising that the experience of the 2d Auxiliary Surgical Group included only two such injuries. The first patient died on the operating table, from cardiac tamponade. The pericardium was distended by hemorrhage from a small laceration of the superior vena cava, and the fragment was recovered free in the pericardial sac.

The second patient was of interest because of the retained foreign body which rested in close apposition to the ascending aorta and moved vigorously with each cardiac pulsation (fig. 30). The vessel wall was presumed to have escaped injury, and the patient was returned to the Zone of Interior without operation overseas.

That this patient was likely to continue well was evident in the case history of another soldier observed in the Mediterranean theater, who had harbored a .38-caliber bullet directly against the ascending aorta for the past 20 years (fig. 31). On fluoroscopy, the bullet was seen to move vigorously with each pulsation of the aorta. In the interim, he had had no symptoms of any kind, and he was returned to the Zone of Interior not because of the presence of the bullet but because of bronchial asthma.

MANAGEMENT OF CARDIAC WOUNDS

Official Policies

The infrequency of wounds of the heart susceptible to surgical management is implicit in the scant attention paid to them in the instructions for wound management issued during World War II. They are not mentioned in the circular letters published in either the Mediterranean or the European theaters or in the "Manual of Therapy" published in the European theater just before D-day. They are also not mentioned in War Department Technical Bulletin (TB MED) 147, which was published in March 1945 and which dealt with the care of battle casualties in the light of the wartime experience to date.

In fact, the only detailed instructions for management of wounds of the heart appeared in the thoracic surgery section of the military manual on neurosurgery and thoracic surgery published in 1943 under the auspices of the Committee on Surgery of the Division of Medical Sciences of the National Research Council (*10*).

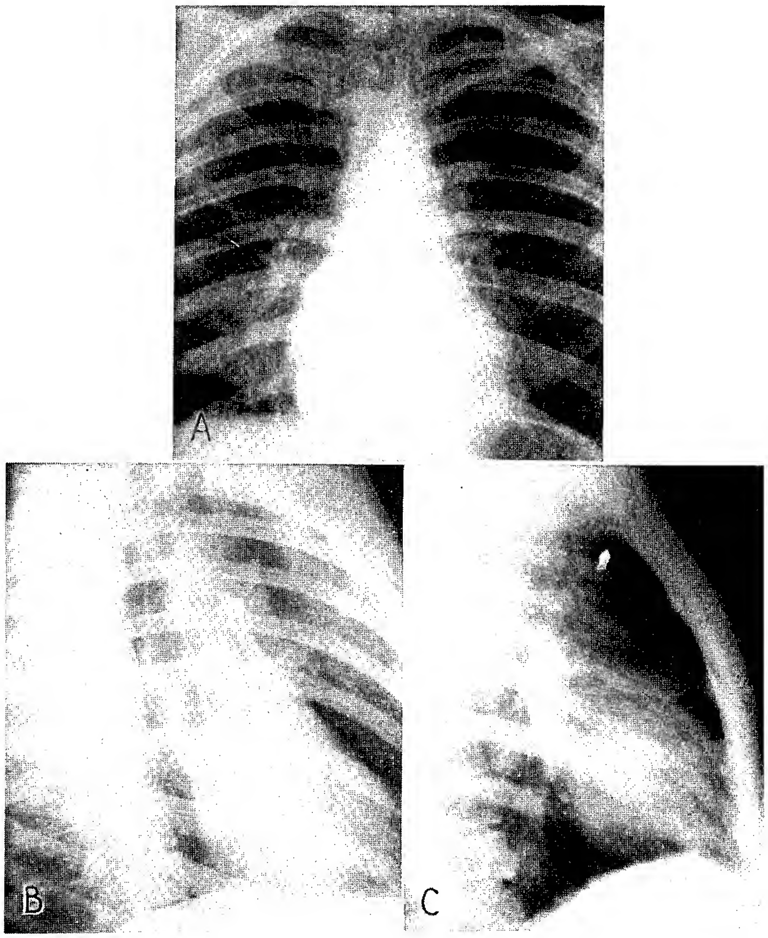

FIGURE 30.—Retained shell fragment in close apposition to ascending aorta. It moved vigorously with each pulsation. A. Posteroanterior roentgenogram. B. Right anterior oblique roentgenogram. C. Lateral roentgenogram.

Policies in the Mediterranean Theater

Although foreign bodies within the heart were not a major problem in base installations in the North African campaigns or later in the Italian campaigns, it early became necessary to establish a policy concerning their management. Discussions by Col. Edward D. Churchill, MC, Consultant in Surgery to the theater surgeon, with the thoracic surgeons in the theater led to the establishment of the following principles:

1. Only foreign bodies in the heart that were causing significant clinical symptoms or giving rise to significant clinical signs were to be removed in over-

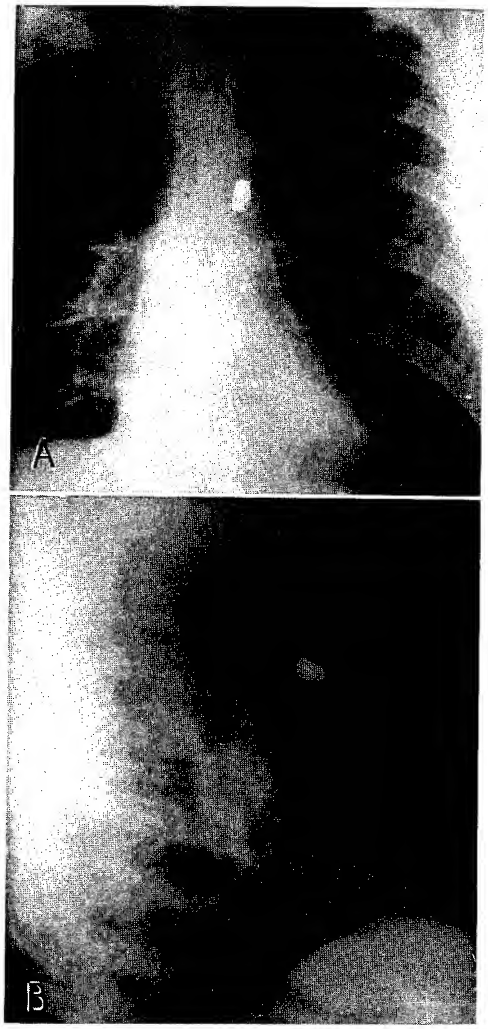

FIGURE 31.—Retained .38–caliber bullet lying directly against ascending aorta, in which position it had been for the past 20 years. Although it moved vigorously with each pulsation of the aorta, the patient had never had symptoms referable to it. A. Posteroanterior roentgenogram. B. Lateral roentgenogram.

sea base installations. All such casualties were to be sent to chest centers, for management by qualified thoracic surgeons.

Two groups of objects were believed likely to give trouble. The first was composed of missiles, particularly low-velocity fragments, lying in the myocardium, without complete penetration of the chambers. These, it was thought, would give rise to continuing intracardiac bleeding or to nonhemorrhagic pericardial effusion or to both. A number of such cases were managed successfully by surgery. The second group was composed of intramyocardial foreign bodies impinging on major coronary vessels, which might give rise to symptoms of coronary arterial insufficiency. Two such cases were treated, with complete relief of anginal symptoms after removal of the objects.

2. It was not believed that so-called chamber foreign bodies; that is, foreign bodies lying in an auricle or ventricle, would be a problem in an oversea theater. On the basis of long-term followup reports it was thought that patients in this group could be safely evacuated to the Zone of Interior for such surgery as might be necessary. On the other hand, if a chamber foreign body migrated intravascularly to the pulmonary vessels, removal in the oversea theater was considered indicated.

Experience confirmed the validity of this policy. Only a small number of true chamber foreign bodies were observed, none of which migrated to the pulmonary vessels or gave rise to difficulty during the period of observation overseas.

Surgical Timing

When a patient with a suspected cardiac wound was encountered in wartime, the decision as to its management could not be based, as in civilian life, solely upon the presence of the wound and the patient's status. In wartime, the heart wound frequently represented only one of several injuries, and both the diagnosis of the cardiac wound and the timing of surgery for it were complicated by the presence of these multiple injuries. As already noted, only half of the cardiac injuries in this series were diagnosed before operation or post mortem, but, in view of the difficult circumstances, the percentage of diagnoses is gratifying rather than otherwise.

Decision as to surgery rested upon two considerations, the type of injury and the presence or absence of a foreign body in the heart or pericardium. Three questions had to be answered:

1. Could the cardiac lesion itself be corrected by surgery?

2. What was the effect of the patient's cardiac status on his ability to withstand surgery for other wounds?

3. Should the surgery be performed at a forward hospital, at the base, or in the Zone of Interior?

When the heart was exposed for any reason at initial wound surgery in a forward hospital, suture of the laceration was best accomplished at the forward hospital. Efficient repair was unlikely in the base section after 10 days

or more had elapsed after the injury. After this lapse, retraction of the edges of the myocardial defect and induration from proliferation of fibroblastic tissue combined to defeat good approximation.

Foreign bodies, however, presented a different problem. When it was certain that a foreign body identified by roentgenologic examination was just within the myocardium or had merely penetrated the pericardium, it was best to postpone surgery for 7 to 14 days and to evacuate the patient to a base center unless there were early and continued episodes of bleeding or cardiac dysfunction. Continued bleeding from a cardiac wound was always an indication for prompt thoracotomy. Otherwise, surgery was seldom an emergency. The dearth of diagnostic facilities and the lack of time for unhurried study in forward installations made accurate localization in them difficult or impossible.

Specifically, indications for delayed removal of foreign bodies included cardiac pain, arrhythmia, abnormalities in previously normal electrocardiographs, and suspected intrathoracic hemorrhage.

Preoperative Management

Resuscitation of patients with recognized cardiac wounds followed standard principles. Originally, in accordance with the work of Beck (*6*), it had been thought that if tamponade existed or was suspected, it would be of no value to give blood or any other fluid intravenously, since it could not reach the heart. The experimental work of Cooper, Stead, and Warren (*11*) shortly before the war had shown that rapid intravenous infusion, with the subsequent increase in blood volume, enabled dogs to withstand considerably higher intrapericardial pressure than when this measure was omitted. Elkin (*3*) had also shown its clinical value. Rapid blood transfusions were therefore strongly recommended as part of the preoperative routine.

TECHNIQUE OF CARDIAC SURGERY

When a cardiac wound was considered in need of surgical repair or when such a wound was suspected, adequate exposure through an elective approach was mandatory. The tragedy of inadequate exposure was well illustrated by a case in the 2d Auxiliary Surgical Group experience in which exsanguination occurred from an unsuspected wound of the right auricle. The surgical incision, a low posterior thoracotomy, was intended for a thoracoabdominal wound and was not suitable for control of auricular hemorrhage.

Surgeons of the 2d Auxiliary Surgical Group believed very strongly that extrapleural techniques should not be employed, however desirable they might be in civilian life. In the Duval-Barasty type of extrapleural surgery, both auricles and ventricles were exposed simultaneously, and the argument was advanced that with such exposure, there was less possibility for missiles to

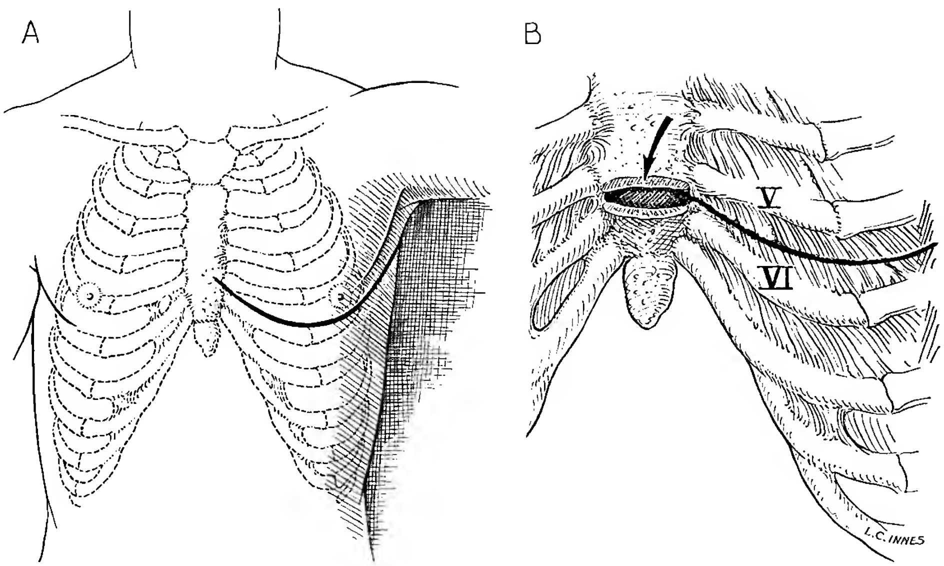

FIGURE 32.—Technique of cardiac surgery. A. Left anterolateral transpleural incision to expose left ventricle. B. Exposure of right ventricle aided by transection of sternum.

migrate from one chamber to the other. Exposure for posterior lesions, however, was not satisfactory by the extrapleural technique. Such operations always took longer than operations performed by the transpleural technique, and there was no time for them in the busy wartime operating room. Finally, the intrapleural damage and hemothorax almost always present in these battle-incurred wounds made extrapleural techniques so difficult that they were entirely impractical.

Surgical Approach

An anterior transpleural approach (fig. 32A) was generally most suitable. An intercostal incision was always employed unless the rib in the involved area was badly fractured. The third or fourth intercostal space provided the best exposure for wounds of the auricle and the fifth or sixth interspace for wounds of the ventricle. In general, more of the right ventricle could be exposed through a left-sided than through a right-sided thoracotomy (fig. 32B).

The incision was carried to the sternum, and the internal mammary vessels were ligated and divided. When it proved necessary, an increase in vertical exposure could be obtained by transverse section of the sternum at the level of the intercostal incision.

Usually, according to the suggestion of Beck (*6*), 10 cc. of 5 percent procaine hydrochloride was injected into the pericardial sac several minutes before the heart was exposed. This practice materially cut down the incidence of ectopic beats while manipulations were in progress.

As a rule, the pericardium was found tense, with the cardiac pulsations weak or even imperceptible. If the pericardial wound was found, it was enlarged as necessary. If it was not found promptly, the pericardium was opened between stay sutures. Once intrapericardial pressure was relieved, bleeding became more profuse and cardiac contractions increased in force. The heart wound was occasionally located before blood and clots were removed and before the heart began to beat actively. Suture was simple under these conditions. More often, the wound was not located until free blood and clots had been removed by suction.

Control of Hemorrhage and Rotation of Heart

In ventricular wounds, if the left index finger was placed over the wound, bleeding was usually controlled sufficiently to permit the passage of a suture directly under the finger. The suture, which was left untied, was held in the left hand, so that hemostasis could be secured by traction while other sutures were placed and tied. If the wound was on the diaphragmatic surface, on the posterior aspect of the heart, or behind the sternum, a stay suture was sometimes passed through the apex, by Beck's (*6*) technique, so that the heart could be rotated into a favorable position for suture of the wound.

Surgeons of the 2d Auxiliary Surgical Group found that the hand of the assistant (fig. 25C) made a better retractor than any suture. By this means, the apex of the heart could be rotated forward at least 90°, and cardiac movement was considerably dampened. Spreading the fingers provided a sliding type of retractor which permitted exposure of any portion of the cardiac wall.

If the lesions were anterior, the palming method (Sauerbruch grip) had advantages. By this technique, the third, fourth, and fifth fingers of the surgeon's left hand were passed behind the heart. The index finger was anterior, and the thumb was used as necessary for hemostasis. This technique provided excellent control of both the heart and the bleeding area.

Suture Techniques

Much of the wartime knowledge of actual cardiac suture techniques was owed to the prewar work of Beck (*6*), Elkin (*3*), and Bigger (*4*), in particular (fig. 33). The general techniques which they had promulgated pointed to the direction, and furnished the background, of most cardiac surgery.

Some lacerations in this series were deliberately not sutured, for two reasons: Some were considered too slight to require repair, and some were so located, or were of such a character, that it was thought that attempts at suture might lead to additional difficulties. Among the wounds left unsutured were (1) superficial lacerations of the myocardium 1 or 2 mm. in depth, which were not bleeding, particularly if the left ventricle was involved; (2) round or oval lacerations left after removal of foreign bodies, especially in the apical region; and (3) lacerations near a major coronary artery, in which the risk of

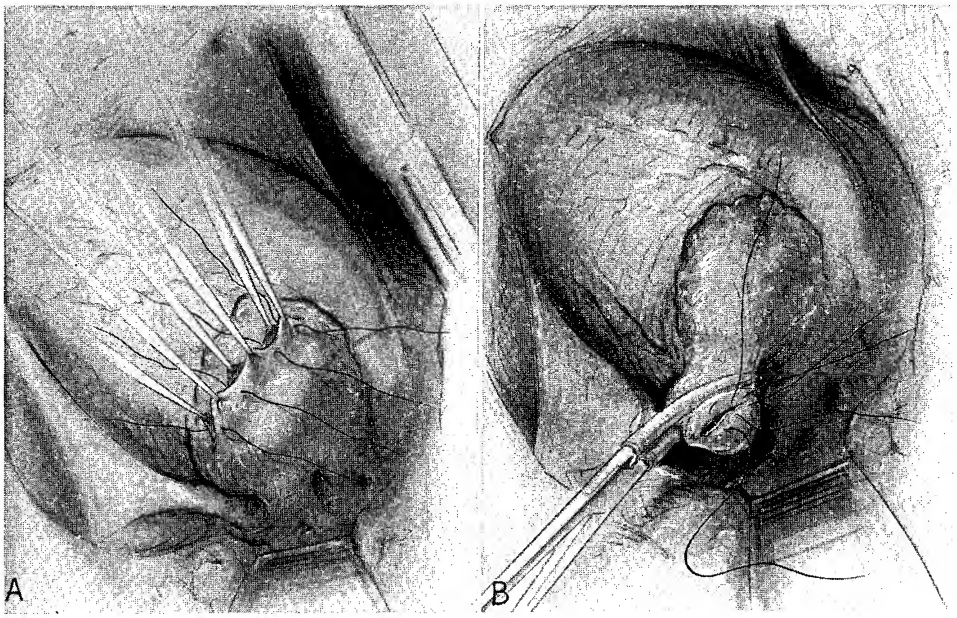

FIGURE 33.—Technique of cardiac surgery. A. Closure of perforating wound of left auricle by modified Beck technique. B. Closure by modified Elkin technique. Occlusion of wound with rubber-shod forceps.

nonrepair had to be weighed against the chances of thrombus formation. Wounds of the coronary vessels were not necessarily fatal. If small branches were bleeding, very careful ligature or suture of the individual branches was highly satisfactory.

Wounds which had penetrated the cardiac chambers were always sutured, even though they were plugged by blood clots and were not bleeding when they were exposed. If they were not sutured, secondary hemorrhage was always a possibility.

In general, it was easier to repair lacerations of the auricle on the right side than on the left. Since the right wall is thinner than the left, repair of wounds in this area was always necessary, on the ground that after repair, the wall was thicker, and the scar from the sutured laceration stronger, than a naturally healed wound. Complete suture or some other type of repair was considered mandatory if the depth of the laceration felt thin or if there was any myocardial bulging. Without adequate suture, aneurysm of the myocardium might develop later. Cases of this kind were reported by Loison (cited by Lilienthal (*12*)).

Large wounds of the auricle deserve special mention. Even wounds as large as 3 cm. might not be exsanguinating because the lung had collapsed against the wound or a clot had formed. The maneuver of covering the defect with the finger in penetrating wounds, as practiced in ventricular wounds, was,

however, not practical in wounds of the auricle because of the thinness of the auricular wall. If sutures could not be placed immediately, the best plan was to grasp each edge of the laceration with fine forceps, which were then approximated, or to use temporary ligatures until sutures could be properly introduced. If the wound was at the edge of the auricle, it would be completely occluded with rubber-shod forceps.

Perforating through-and-through wounds of the chambers could be repaired successfully if both wounds were superficial. No method of exposure was practical for repairing a wound of the posteromesial surface of the right auricle. The only two patients in the 2d Auxiliary Surgical Group series with this type of wound both died of exsanguination, caused by hemorrhage from the free wounds. If the cardiac wound could have been repaired, the mediastinal perforation might have sealed off.

A needle with a small eye or an atraumatic needle was used. Sutures were interrupted and were usually of braided No. 00 or No. 000 silk, preferably oiled or waxed. They were placed as close as possible to the wound edges but did not include them, if this could be avoided (it could not always be avoided in auricular wounds), because of the possibility of thrombus formation. In myocardial defects, sutures were taken into the epicardium and superficial myocardium. No sutures included the endocardium (fig. 23). Great care was taken in the placing of sutures, since necrosis of the wound edges, particularly when the cardiac chambers were involved, could lead to fatal necrosis and secondary hemorrhage. Sutures were tied during systole when possible and always without tension.

Some lacerations, because of loss of substance as the result of the necrosis and contusion of surrounding tissues, were difficult if not impossible to suture completely. Then considerable ingenuity had to be exercised to secure closure, particularly when the laceration extended into a cardiac chamber. Free muscle grafts were useful, and probably should have been employed more frequently than they were. They could be laid in the defect, where they were held in place by fine sutures (fig. 24B). They helped to fill the defect and were also instrumental in checking hemorrhage or myocardial oozing.

As a further reinforcing mechanism, the pericardium was sutured over the area of repair, after establishment of drainage for the pericardial sac into the pleural cavity by a cruciate incision. The edges of the pericardium could be either approximated or imbricated (fig. 24C). This technique, combined with the use of a muscle graft, provided solid repair. A flap of pericardium as an extra layer was also useful when bleeding had not been completely controlled by myocardial suture.

Drainage was provided into the pleural cavity by closing the pericardium so loosely that fluid was able to escape. In the two cases in which this precaution was omitted, pericardial effusion occurred (p. 65).

The chest wall was sutured with careful approximation of the anatomic layers.

ANALYSIS OF CASES

Management

Lacerations and perforations.—Twenty-nine cardiac injuries were visualized at operation and managed as follows:

Complete repair was accomplished in four lacerated wounds (one of the left ventricle, two of the right ventricle, and one of the right auricle and right ventricle).

Partial repair was accomplished in two lacerations of the left ventricle.

Complete repair was accomplished in 10 perforating or penetrating wounds (6 of the left ventricle, 1 of the right ventricle, 1 of the left auricle, and 2 of the right auricle).

Repair was attempted but proved impossible in two perforated wounds of the right auricle.

No repair was attempted in 11 wounds, including 10 lacerations (8 of the left ventricle, 1 of the right ventricle, and 1 of the right auricle), and 1 perforating wound of the right ventricle.

Foreign bodies.—It was the policy in the Mediterranean theater to be extremely conservative about the removal of foreign bodies in forward hospitals or, indeed, in any oversea hospital. Of the 29 retained missiles in the 75 cardiac wounds in the 2d Auxiliary Surgical Group experience, only 9 were removed, as follows:

Four (of four) were recovered from the pericardium.

One (of three) was recovered from the pericardial sac.

Three (of ten) were recovered from the myocaridum; five others were found at autopsy.

One (of four) was recovered from the cardiac chambers; three others were found at autopsy.

The majority of fragments not removed were small, 0.5 cm. or less in diameter. In some cases, the condition of the patient did not warrant an extended search for them. The two foreign bodies not removed from the pericardial sac were not identified positively, but from the roentgenologic evidence and operative findings, it was considered highly likely that they were present.

Of the eight foreign bodies found only at autopsy, the missile was directly responsible for one death, because of an embolus to the heart (case 7, p. 80) and possibly for a second death (case 8, p. 80).

Postoperative Observations and Complications

Certain cardiac abnormalities were observed in some of the patients who survived surgery:

Eight developed friction rubs, some of which were audible for as long as 3 weeks.

Two patients had apparent myocardial accidents, presumed to be infarctions. One occurred in the single stab wound in the series (p. 84). The other patient developed a typical coronary occlusion 24 hours after operation, with transient auricular fibrillation, precordial pain, and circulatory collapse. This patient had presented extrasystoles before operation, and at operation, it was necessary to ligate a small bleeding terminal branch of the anterior descending artery. In addition, he had a clean superficial laceration of the cardiac apex, which was not repaired.

One patient had a transient pneumopericardium.

One patient developed hemiplegia after repair of a laceration of the left ventricle. One may speculate whether mural thrombi formed after operation.

Two patients developed massive pericardial effusions. In neither instance was the pericardium drained at operation. Both did well with pericardicentesis, and there were no apparent sequelae.

Four other patients had delayed pericardial effusions between 2 and 6 weeks after injury, for no apparent reason. All recovered under conservative management. The clinical course suggested an irritative phenomenon rather than a flareup of latent infection. British observers in the Mediterranean theater, who observed a few similar cases, accepted this development as an indication for removal of any retained foreign bodies as soon as the acute reaction subsided. The limited U.S. experience, as well as theoretical considerations, suggested a more benign interpretation, which remained for the future to clarify.

Fibrinous pericarditis developed in four cases and quite likely was present in others in which it was not clinically apparent. The removal of dressings and bandages to establish this fact would not have been justified. In the affected patients, electrocardiograms usually exhibited the expected changes in the QRS complexes (low voltage), with lesser degrees of alteration in the T-waves and S–T intervals.

Purulent pericarditis occurred in one case in the series in which the diagnosis of pericardial injury was missed at first:

Case 11.—This patient sustained a severe penetrating shell-fragment wound of the epigastric region on 3 June 1944. Debridement revealed no pleural penetration, and no foreign body was visualized. Laparotomy revealed no intra-abdominal injury.

Five days after wounding, the patient became increasingly dyspneic, and cardiac enlargement was noted. Digitalis was administered, on a diagnosis of myocardial insufficiency. When he was admitted to a thoracic surgery center on 11 June, 600 cc. of dark, bloody fluid, without odor, was removed from the pericardium, with prompt relief of dyspnea. Systemic penicillin therapy was begun. Five days later, only 15 cc. of fluid was obtained on pericardial aspiration, but 2 days later, 1,000 cc. was obtained. The patient became progressively more febrile, and on 17 June, the fluid removed (400 cc.) had an offensive odor, showed early purulent transition, and on direct smear was found to be teeming with organisms.

Pericardiostomy was performed immediately, by removal of segments of the fourth and fifth costal cartilages. A large metallic foreign body, surrounded by a large piece of cloth, was found in the posterior recess of the left pericardial sac; it had driven

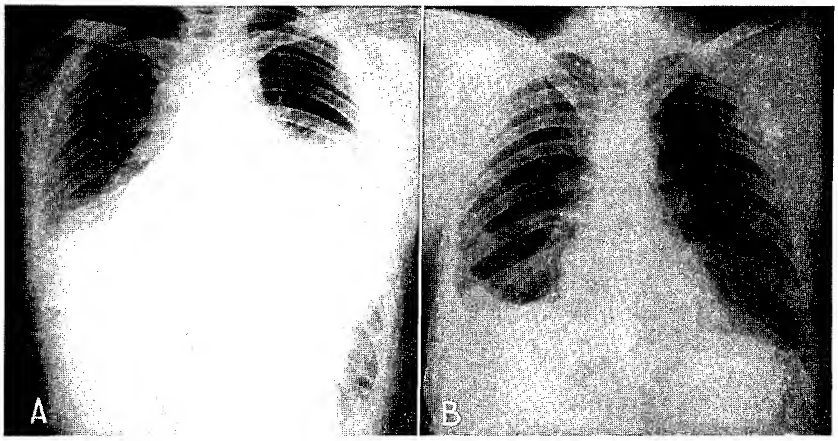

FIGURE 34 (case 11).—Suppurative pericarditis. A. Posteroanterior roentgenogram showing extent of accumulated fluid in pericardium. Aspirated fluid showed early purulent transition and had a foul odor. B. Same, 3 weeks after pericardial drainage.

itself partly through the pericardium and into the left pleural space. The missile, with its cloth investment, was removed, and the pericardium was emptied by suction and was tacked to the pectoral fascia to keep it widely open. No other provision for drainage was made. Cultures were reported positive for proteolytic clostridia.

The patient made a very rapid recovery, and the pericardial cavity was rapidly obliterated. There were no episodes of recurrent dyspnea or paradoxical pulse. The fever subsided promptly, and the patient was up and about 18 days after operation.

Comment.—The foreign body in this case was not visualized (fig. 34A) by roentgenograms because of the superimposition of the heart shadow and the density of the fluid in the pericardium. Its presence in the pericardium was suspected because of the failure to visualize it elsewhere and the nature of the wound. The patient's rapid convalescence is explained by the fact that drainage was instituted early, before the pericardial fluid became thick and intensely purulent. As a result, there was no recurrence of dyspneic episodes and no irregularities of the pulse. There was also prompt obliteration of the pericardial sac (fig. 34B). Fibrinous deposition of exudate on serosal surfaces is an important factor in delayed convalescence in such cases and furnishes an urgent reason for early drainage.

Fatalities

There were 30 deaths in the 75 cardiac injuries managed by the surgeons of the 2d Auxiliary Surgical Group, 3 among the 18 pericardial injuries and 27 among the 57 myocardial injuries.

All three deaths in the pericardial group occurred 48 hours or more after operation, and none could be attributed to the cardiac wound per se. Of the 27 deaths in the myocardial injuries, 20 were, however, directly attributable to the cardiac wounds. The seven remaining fatalities were variously attributable to associated wounds or to shock, bronchopneumonia, and anuria.

Ten cardiac wounds were seen only at autopsy, as follows:

Four lacerated wounds, including one of the left ventricle, one of the right ventricle, and two of both ventricles.

Six perforated wounds, including one of the left ventricle, one of the right ventricle, one of the left auricle, and three of the right auricle.

Causes of death.—Exclusive of the 3 deaths in the 18 pericardial injuries, the 27 deaths in the 57 wounds of the heart proper were distributed as follows:

Eleven deaths, six due to cardiac causes, in sixteen pure contusions. Three of these cardiac deaths were due directly to myocardial lesions and usually occurred suddenly, from infarction or arrhythmia. In the three other cases, the heart wound played an essential contributory part in the fatality but was not the only cause.

Five deaths, four due to cardiac causes, in the ten lacerations associated with contusions.

One death, due to the myocardial lesion, in the ten pure lacerating wounds.

Nine deaths, eight due to cardiac causes, in the nineteen perforating or penetrating wounds. In four cases, the fatality was due to exsanguinating hemorrhage from the cardiac wounds, and in two cases to tamponade.

One death, in a myocardial lesion, due to a cardiac embolus.

An analysis of the cardiac deaths (table 6) shows that 15 of the 20 followed wounds of the ventricles.

Time of death.—The distribution of the 27 deaths in the series in relation to the time of the fatality was as follows:

Two before operation, both as the result of the cardiac wound.

Ten, including four in thoracoabdominal injuries, before surgery was completed or immediately after operation. Eight were considered due to the cardiac wound.

Four, including three thoracoabdominal wounds, between 1 and 5 hours postoperative. Three were considered due to the cardiac wounds.

TABLE 6.—*Distribution of 27 deaths in 56 combat-incurred cardiac injuries* [1]

Type of injury	Number of cases	Number of deaths		Anatomic distribution of cardiac deaths				
		Cardiac	Other	Ventricles			Auricles	
				Right	*Left*	*Both*	*Right*	*Left*
Contusions	16	6	5	2	3	1		
Lacerations	10	1			1			
Contusions and lacerations	10	4	1	1	1	2		
Perforating or penetrating	19	8	1	1	2		4	1
Embolus of heart	1	1		1				
Total	56	20	7	5	7	3	4	1

[1] This table does not include a self-inflicted stab wound, from which the patient recovered. It also does not include 18 combat-incurred pericardial injuries, 3 of which were fatal.

Two between 6 and 12 hours postoperative. Neither was due directly to the cardiac wound.

Six, including one thoracoabdominal wound, between 12 and 24 hours postoperative. Four were considered due to the cardiac wound.

Three, including two thoracoabdominal wounds, after 24 hours. All were considered due to the cardiac wound.

Of the 20 deaths considered directly due to the cardiac wound, 2 occurred before operation, 8 during or immediately after operation, 3 within 5 hours after operation, 4 within 13 to 24 hours postoperative, and 3 after 24 hours postoperative.

Responsibility for cardiac fatalities.—In 20 deaths attributed to wounds of the heart, either surgery was not done at all, or corrective surgery was not completed. An analysis of these cases indicates that in eight, surgery would probably have benefited the patients and that in one other case, it might possibly have been beneficial. In the other 11 cases, surgery would not have been useful, or more extensive surgery than was carried out would have been useless. Of these 11 casualties, 4 were in such poor condition when they were first seen that they died promptly, either before or during operation. Another, thought to be in good condition, died suddenly during operation, and three others, also thought to be in good condition, died suddenly soon after operation. The other three patients in this group died after operation, soon after symptoms of myocardial infarction had become evident.

When the analysis of the possible benefits of surgery, or of more complete surgery, is made in these 20 cases from the standpoint of the causative lesion, the following facts emerge:

1. The six casualties with contusions could not have benefited by operation. This is not a lesion which is ever benefited by surgery, nor is it a condition in which early operation for other causes, however necessary it may be, is well tolerated.

2. Surgery would not have been useful in the single fatal lacerating wound uncomplicated by other cardiac damage. The patient had a pericarditis produced by contamination with gastric contents, though the exact role of the infection in the fatal outcome cannot be stated precisely.

3. Operation would not have been useful in four cases of myocardial lacerations and contusions in which it was omitted, nor would additional surgery have been beneficial in a fifth case in which the laceration was repaired. Damage was lethal in all four of these cases. In three, the anterior descending branch of the left coronary artery presented a traumatic thrombosis for at least half its length, and the fourth patient had an early pericarditis produced by contamination from gastric contents. A fifth patient, with a myocardial laceration and contusion, might possibly have been helped by surgery. He died suddenly, 4 hours after debridement of the thoracic wound. At autopsy, a shell fragment 15 by 10 by 10 mm. was found in contact with the sternum, lying in a shallow, contused, lacerated wound of the right ventricle at the base of the pulmonary

conus. It is possible that the continued presence of this missile was responsible for propagating fatal ectopic stimuli. The pericardium contained 150 cc. of liquid blood, but the sac was not tense, and the mode of death did not suggest that pressure from tamponade played any part in the fatal outcome.

4. Operation would probably have been useful in the fatal case in which the foreign body became embolic to the heart.

5. The largest group of cases in which surgery might have been beneficial consisted of seven penetrating or perforating wounds of the cardiac chambers. Repair of the defect would probably have succeeded in six of these cases and might have helped in the seventh. Four of the patients died of exsanguination, one in the shock ward, two on the operating table, and the other of an unrecognized perforating wound of the right auricle. In this case, original hemorrhage had apparently ceased when debridement of the thoracic wall was done, but rapid exsanguination occurred before additional surgery was performed 36 hours after the injury.

There were two instances of tamponade in these seven cases. One was entirely unsuspected until autopsy. The second was recognized too late for control, though it is doubtful that the patient could have survived, in view of the severe associated thoracoabdominal wounds.

The mode of death in the remaining (seventh) case in this group is not entirely clear. Death occurred suddenly and was considered due to myocardial dysfunction. The patient had a through-and-through wound of the left auricle, and there was approximately 100 cc. of blood in the pericardium, without any evidence of tamponade. It is speculative that repair of the defects might have been successful but quite obvious that a man with such injuries could not survive very long without surgery.

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CHAPTER III

Thoracoabdominal Wounds

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GENERAL CONSIDERATIONS

Definition.—The term "thoracoabdominal wound" was reserved in World War II for a wound in which a single missile was responsible for damage to structures of the chest and the abdomen. In approximately 90 percent of all cases, the missile entered the chest and passed into the abdomen. As a rule, the term "thoracoabdominal injury" implied a perforation of the diaphragm. Occasionally, a missile that entered the chest could transmit sufficient force through an intact diaphragm to produce an abdominal injury, but this was most unusual. A wound of the so-called bare area of the liver produced by a fragment that entered the chest and perforated the diaphragm was considered a true thoracoabdominal wound.

The term "thoracoabdominal wound" should never have been used, as it occasionally was, for wounds in which both serous cavities were injured by separate missiles. The distinction is important. The management of a combined thoracic and abdominal wound inflicted by separate missiles and without perforation of the diaphragm differed considerably from the management of a thoracoabdominal wound in which the injury of both cavities was produced by the same missile and in which perforation of the diaphragm was a factor. Thoracoabdominal and combined thoracic and abdominal wounds resembled each other in one respect, however, that both carried very high mortality rates.

Incidence.—There was not complete agreement as to the incidence of these wounds.[1] They accounted for about 5 percent of all admissions for battle-incurred wounds in Seventh U.S. Army hospitals. Maj. (later Lt. Col.) Lawrence M. Shefts, MC, and Capt. (later Maj.) Ernest A. Doud, MC, who had a representative forward experience, found that thoracoabdominal wounds represented about a quarter of their intrathoracic wounds. The 903 thoracoabdominal injuries treated by the 2d Auxiliary Surgical Group amounted to almost 40 percent of the 2,267 intrathoracic injuries which they encountered.

Management in field hospitals.—About a quarter of the battle-incurred injuries treated in field hospitals in the Mediterranean theater were thoracoabdominal injuries. Since casualties with these injuries were always nontransportable, practically all were treated in these forward hospitals. The

[1] Official statistics for thoracoabdominal injuries appear in the first volume dealing with thoracic injuries (chapter II, tables 8–11).

746-941v—65——9

occasional casualty treated in an evacuation hospital had an injury that had escaped recognition in the field hospital. The management of thoracoabdominal injuries in base hospitals consisted of the management of complications and the care and closure of colostomies.

As a group, casualties with thoracoabdominal wounds presented the severest injuries of all battle casualties; furnished a high proportion of the admissions to field hospitals, where, as just noted, most of them were treated; and had the highest case fatality rate of any group admitted to them.

These wounds furnished the most important single indication for surgery of thoracic injuries in a field hospital, for two reasons, (1) that resuscitation was not complete without surgical repair of the intraperitoneal damage, and (2) that in this type of wound, immediate surgery was necessary to prevent or control intraperitoneal contamination. In thoracoabdominal wounds, whether the diagnosis was established or merely probable, surgery was indicated as soon as cardiorespiratory stability permitted.

Attention has been called elsewhere to the necessity for thoracic surgeons assigned to field hospitals to be able to do intra-abdominal surgery (vol. I). The large number of thoracoabdominal wounds that had to be handled in these installations was further proof of the need for this dual ability. Even though the majority of casualties with injuries limited to the thorax could be evacuated to the evacuation hospitals after resuscitation, if not before, a single team could not handle the remainder of the casualties in this group plus all of the casualties in the thoracoabdominal group. Thoracoabdominal injuries were practically always very serious, and a great deal of time was consumed in resuscitation and at operation. A desirable plan, when available personnel permitted its use, was to assign a senior thoracic surgeon to a field hospital and place two teams under his direction. In this way, he could supervise the management of all serious thoracic and thoracoabdominal wounds without attempting the usually impossible task of managing them all personally.

PATHOLOGIC PROCESS

The wound of entrance in thoracoabdominal wounds was in the thorax in the great majority of cases. In the 903 such wounds encountered by the 2d Auxiliary Surgical Group, the missile entered through the chest 837 times and through the abdomen 66 times.

Thoracic injuries.—In most instances, the entering missiles caused fractures of the ribs; the level of the fractures tended to correspond with the zone of the diaphragm. In only 3 of the 903 wounds just mentioned was the site of the costal fracture above the sixth rib posteriorly or the fourth rib anteriorly. The paucity of wounds in the upper chest is probably to be explained by the smaller size of the target and by the lethal effect of missiles which entered the thorax in a cephalad direction; these patients did not survive to reach a hospital.

Pulmonary damage varied according to the site of injury. When a costophrenic angle was crossed, damage was usually minimal. If the wound of entrance was elsewhere, there was usually a perforation or a laceration of the lung. Contusions were less frequent. Hemorrhage was present along the track of the missile and for 1 to 3 cm. beyond it. In an occasional case, a segment of the lung was found amputated.

The mediastinum was injured 30 times, the heart 14 times, and the pericardium alone 13 times in these 903 cases. There was only one injury of the esophagus.

In most cases handled by the 2d Auxiliary Surgical Group, on whose material all of the following statements are based, the pulmonary wound was in the peripheral portions of the lower lobes because the missiles most often entered through the lower chest in the zone of the diaphragm. Injuries of the middle lobe and of the lingula of the left upper lobe were much less frequent.

Diaphragmatic injuries.—Injuries to the diaphragm (fig. 35) fell roughly into three categories:

1. Small single or double perforating wounds.
2. Large lacerated wounds.
3. Avulsion of the diaphragm from its attachment to the chest wall.

The wounds were almost equally distributed between the right (435 cases) and the left (448 cases) sides. In 20 cases, the diaphragm was perforated bilaterally.

Herniation of abdominal contents through the diaphragm was recorded 57 times. In 17 instances, only the omentum protruded. The explanation of evisceration was the physiologic fact that pressure is normally lower within the chest than within the abdomen. As a result, the spillage of gastric and intestinal contents into the chest was always a possibility when the diaphragm had been wounded.

Intra-abdominal injuries.—The liver took the impact of missiles which entered on the right side. It was involved in 407 of the 435 right-sided injuries. In the order of frequency after wounds of the liver (table 7) were wounds of the right kidney, colon, stomach, small bowel, and gallbladder. On the left side, the spleen, stomach, and colon took the impact of most missiles entering on that side. In the 448 left-sided wounds, the spleen was injured 272 times, the stomach 167 times, and the colon 145 times.

There was no evidence of involvement of the thoracic duct in these 903 cases. The assumption is that casualties with such injuries seldom survived long enough for their condition to be recognized.

Tension pneumothorax of peritoneal origin.—In the 55 thoracoabdominal wounds encountered by Lt. Col. John M. Snyder, MC, and Maj. Frank Tropea, Jr., MC, 24 of which were left-sided, there were 2 instances of tension pneumothorax of peritoneal origin. This condition, it was thought, had not previously been described. In each instance, the wound of entry was in the lower left chest, and in each, there was a large perforation of the anterior wall

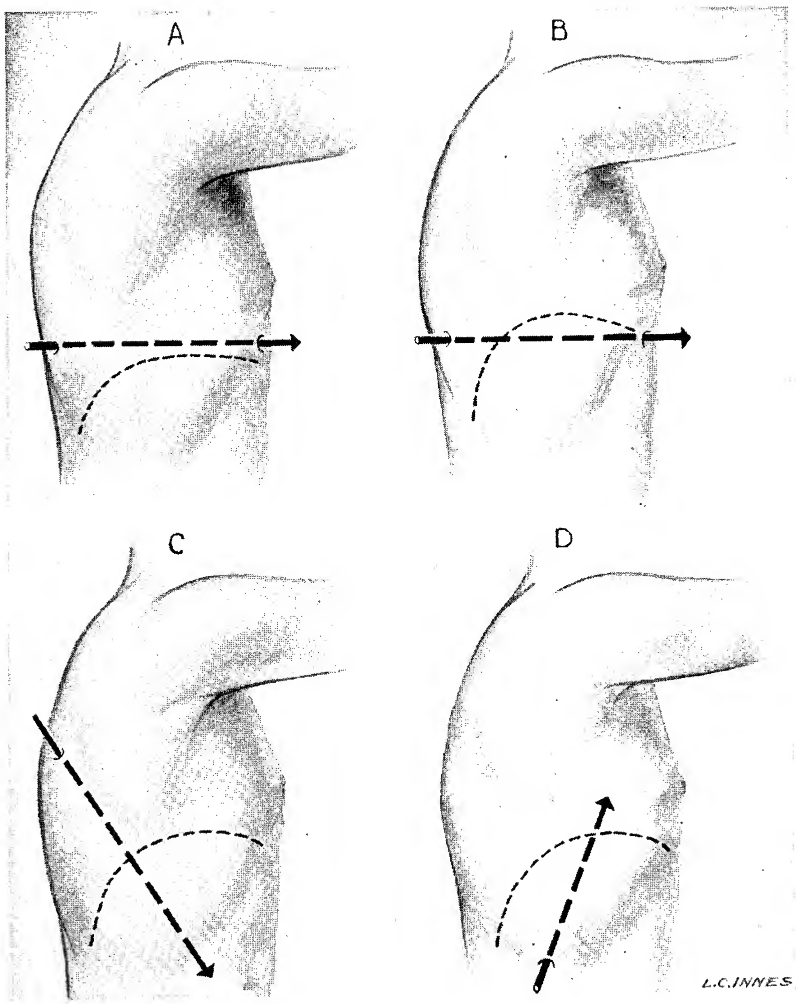

FIGURE 35.—Types of wounds of diaphragm possible from penetrating or perforating missiles. A. Through-and-through wound of lower chest. On inspiration, the wound may be purely thoracic. B. Same type of wound, which may be thoracoabdominal on expiration. C. Thoracoabdominal wound with, as usual, missile entering chest first. D. Thoracoabdominal wound with missile entering abdomen first.

of the stomach, with a resultant outpouring of a large amount of air through the lacerated diaphragm. In the first case, the diagnosis was not made, and death occurred in the course of laparotomy. In the second, in which the condition was recognized several hours after the patient was first seen, closed drainage was instituted, and recovery was uneventful.

Theoretically, there seems to be no reason why tension pneumothorax of peritoneal origin should not be possible under the circumstances described,

TABLE 7.—*Frequency of wounds and case fatality rate in 903 thoracoabdominal wounds according to combinations of viscera*

Combinations of organs	Cases	Deaths	Case fatality rate
Liver alone	297	35	11. 7
Liver and kidney	59	14	23. 7
Liver and stomach	30	11	36. 6
Liver and small intestine	9	1	11. 1
Liver and spleen	7	3	42. 8
Liver and right colon	7	4	57. 1
Liver and left colon	3	1	33. 3
Liver, stomach, and colon	8	5	62. 6
Liver, kidney, and right colon	5	4	80. 0
Liver, stomach, and biliary tract	6	4	66. 6
Liver, stomach, and spleen	11	3	27. 2
Liver, small intestine, and left colon	6	5	83. 3
Stomach and spleen	43	18	41. 8
Stomach, spleen, and left colon	8	4	50. 0
Stomach, spleen, and kidney	9	3	33. 3
Stomach, spleen, and pancreas	3	2	66. 6
Stomach and left colon	8	2	25. 0
Stomach, small intestine, and colon	8	2	25. 0
Stomach and kidney	4	1	25. 0
Spleen alone	95	10	10. 5
Spleen and kidney	27	4	14. 8
Spleen and left colon	19	4	21. 0
Spleen, kidney, and left colon	12	6	50. 0
Spleen and small intestine	9	0	--------
Kidney alone	11	4	36. 6
Left colon alone	18	6	33. 3
Left colon and small intestine	6	3	50. 0
Peritoneal cavity (penetration only)	26	3	11. 5
All other combinations [1]	115	73	63. 4

[1] When five organs or more were injured, the case fatality rate was 100 percent.

though before autopsy established it in the fatal case, some doubt had been felt about it. A tension pneumothorax of peritoneal origin could scarcely occur in a thoracoabdominal wound on the right, but the possibility of what might be termed an internal sucking wound could reasonably be considered on the left side. In this variety of wound, small quantities of air and intestinal contents could be aspirated into the chest during the act of respiration, and the repeated aspiration of small quantities would alter the intrapleural pressure and lead to pulmonary collapse unless the sucking was promptly corrected.

During the laparotomy for a left-sided thoracoabdominal wound, an injury that originated as an internal sucking wound would become an external sucking wound as soon as the peritoneum was opened. This is apparently what happened in the fatal case in this series. Next to the control of active hemorrhage,

therefore, closure of the lacerated diaphragm was the first duty of the surgeon who operated on a thoracoabdominal wound through a laparotomy incision. On the right, the liver usually sealed off the diaphragmatic wound.

In the early days of the war, many laparotomies were performed without endotracheal anesthesia, and as a result, when the abdomen was opened, a tension pneumothorax developed through the perforation in the diaphragm. This complication ceased to be a problem after endotracheal anesthesia was in general use and surgeons became aware of the possibilities of tension pneumothorax of this origin.

DIAGNOSIS

In general, if the patient had a single wound of the thorax and a single wound of the abdomen, the diagnosis was obviously a combined thoracic-abdominal wound. If both wounds were in the abdomen, there was little possibility of diaphragmatic injury unless the costal cage was involved. If both wounds were thoracic and if one was below the level of the fourth rib anteriorly, a thoracoabdominal injury might or might not be present.

Since not more than 10 percent of the missiles in thoracoabdominal wounds entered the body via the abdomen, the chief difficulty from the diagnostic standpoint was in determining the presence or absence of abdominal injury in a patient with a known thoracic wound, in every one of which penetration of the abdomen had to be considered as a possibility until the injury was excluded. There was no problem when roentgenologic examination showed the retained foreign body to lie within the chest or showed that it had entered the abdomen. The diagnostic difficulties were posed by the missiles that perforated the chest in the so-called diaphragmatic zone or penetrated it and lodged in the vicinity of the diaphragm.

Anatomic and Physiologic Considerations

The most practical method of diagnosing a thoracoabdominal wound was to keep constantly in mind that the diaphragm might be involved in any thoracic injury, most particularly in any injury occurring in the area bounded superiorly by the anterior end of the fourth rib and posteriorly by the level of the seventh rib, down to and including the twelfth rib at its inferior level (fig. 36).

Both physiologic and anatomic facts had to be borne in mind in making the diagnosis. It could be assumed that the pleural reflection follows, with reasonable accuracy, the outline of the periphery of the ribs and the costal cartilages. For diagnostic purposes, the thickness of the diaphragm could be ignored, and the peritoneum could be assumed to be in contact with the diaphragmatic surfaces of the pleura. The diaphragm, however, is not an immobile structure which forms a perfectly horizontal partition between the chest and

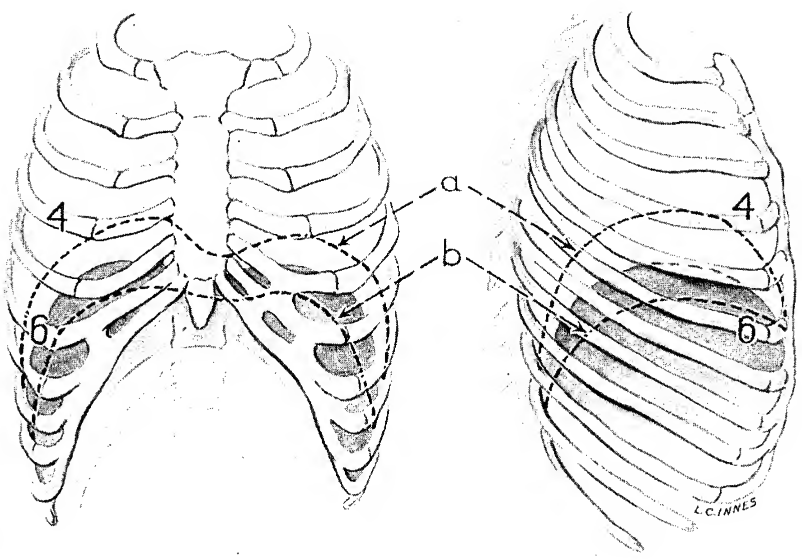

FIGURE 36.—Schematic showing of maximum expiratory excursion of diaphragm. In deep expiration (a), it can reach as high as the superior border of the fourth rib anteriorly. Note depth of costophrenic sulcus on inspiration (b) draws the diaphragm down to the sixth rib.

the abdomen. In these circumstances, diagnosis would be much simpler. Instead, the variables caused by its uneven configuration and the distance through which it can move, tremendously increased its susceptibility to injury, and, in turn, the susceptibility of abdominal organs to involvement in the wound.

Because of the movement of the diaphragm, any wound of the entire lower left hemithorax might penetrate the division between the thorax and the abdomen (fig. 36). Any wound below the seventh interspace posteriorly or the fourth rib anteriorly might injure the diaphragm if the patient was in the expiratory phase of respiration at the time. Since the pleural reflection extends down to the attachments of the diaphragm to the ribs and the costal arch, any wound at the level of the twelfth rib or above posteriorly, or any wound that involved the costal arch or above anteriorly, had to be considered a possible thoracoabdominal injury.

If the range of motion of the diaphragm on deep inspiration and expiration were kept in mind, the cavities and organs involved in a wound of the chest might reasonably be predicted by lining up the wounds of entrance and exit if the injury were perforating, or by lining up the wound of entrance with the point at which the missile was lodged within the body if the injury were penetrating. Any missile, therefore, which passed through the area extending from the level of the twelfth rib posteriorly to the level of the fourth rib anteriorly might or might not have entered both the pleural and the peritoneal cavities.

Since many wounds were inflicted while the soldiers were prone, the increase in intra-abdominal pressure created by this position further raised the upper limits of the diaphragm.

If the patient was in deep expiration at the time of wounding, the diaphragm, with the spleen and stomach, might rise high enough into the thoracic cavity to be injured by a missile that had entered the chest at the fourth interspace. If the wounding had occurred during the expiratory phase of respiration, the anatomic position of the wounds in the chest wall might be quite cephalad and yet there might be a tear in the diaphragm and damage to the peritoneal organs. In one casualty, for instance, in whom the wound of entrance was in the fourth interspace just medial to the left nipple and the wound of exit was in the seventh interspace in the left midaxillary line, the diaphragm was perforated and the spleen was injured.

Projection of Course of Missile

The most reliable and most helpful information in thoracic injuries in which involvement of the abdomen was not evident by clinical means was obtained by projecting the probable course of the missile. Roentgenologic examination was therefore essential in every penetrating wound of the chest, no matter how insignificant it might seem, if only because the location of the wound of entrance was occasionally extremely misleading in relation to the course of the missile within the body.

Both anteroposterior and lateral films were made, with overexposure for both abdomen and chest. They were preferably made in the sitting position. Patients in severe shock, who could not tolerate the upright position, were examined by anteroposterior exposures made in the prone position.

When the information derived from films in two planes was correlated with its point of entrance, the course of the missile could be projected and a decision made concerning the possibility of intra-abdominal damage.

Missiles tend to travel in a straight line if they are not deflected. The experience of most surgeons who treated large numbers of war wounds was, as pointed out elsewhere (vol. I), that stories of missiles which entered at one point and caromed around at a tangent before making their exit or lodging at some point within the body were the exception. There were occasional instances in which the course of the missile was bizarre because it had struck a bony structure tangentially, but these injuries, again, were exceptional. Many superficially bizarre pathways could also be explained by investigation of the position that the casualty was occupying when he was injured. Inquiry on this point was made whenever the patient was sufficiently oriented to furnish the information.

On the other hand, an occasional thoracoabdominal injury diagnosed for the first time at a general hospital made it clear that exceptions to these generalizations sometimes occurred. In one such injury, reported by Lt. Col. John Burke, MC, and Maj. Theodore T. Jacobs, MC, for instance, a wound of

entrance in the region of the right scapula and a wound of exit in the right groin were considered to be individual wounds. They proved to be from the same missile. Fortunately, the delay in operation was not attended with serious consequences.

Clinical Considerations

Part of the diagnostic confusion in some thoracoabdominal wounds was caused by the overshadowing of symptoms and signs referable to the abdominal injury by the more urgent symptoms and signs of the chest injury. The thoracic component of the injury could give rise to pain in the chest wall, hemoptysis, hemothorax or hemopneumothorax, dyspnea, cyanosis, and wet lung.

Since thoracic wounds that did not involve the abdomen were frequently associated with pain and spasm of the upper abdomen (vol. I), these phenomena did not furnish a reliable indication of abdominal injury. Abdominal tenderness and rigidity were also often present; in such cases, a useful differential point was that deep tenderness and rebound tenderness were never elicited in chest wounds. If time could be spared, a differential diagnosis was sometimes clarified by paravertebral or intercostal block. The results were not always conclusive, but when there was prompt relief of pain, abdominal involvement could usually be excluded. Pain in the shoulder was not a universal symptom. When it was present, it pointed to an injury of the diaphragm.

Although nausea and vomiting sometimes occurred in thoracic injuries, they were not common, and their presence lent strength to the possibility of abdominal involvement. The demonstration of active peristalsis suggested that if abdominal injury had occurred, a hollow viscus was not involved. Most surgeons, however, could recall casualties in whom peristalsis had been observed even with wounds of the colon. Peristalsis frequently persisted when the injury was limited to the spleen, liver, or kidney. Wounds of all of these organs were associated with a paucity of symptoms and signs referable to the abdomen.

If a hollow viscus was injured, prompt surgery was imperative, but it was important to remember that injuries of solid viscera could also be extremely serious. A casualty might bleed to death from a damaged spleen, or grave or even fatal bile empyema might be the consequence of an overlooked wound of the liver.

Other Diagnostic Aids

The presence of blood in gastric contents, whether vomited or aspirated, was suggestive of abdominal injury, though it was not conclusive, since it might have originated from a wound of the lung.

Examination of a voided or catheterized specimen of urine was part of the diagnostic routine. The absence of blood in the urine was not conclusive, but its presence furnished valuable information as to the course of the missile in relation to the urinary tract.

746-941v—65——10

Such diagnostic refinements as pneumoperitoneum were not practical in forward hospitals.

EXPLORATION

Indications

The final diagnosis of a thoracoabdominal wound was based on the following considerations:

1. Inspection of the wound or wounds.
2. The projection of the suspected course of the missile from the wounds of entrance and exit if the injury were perforating or from roentgenologic localization of its position if the injury were penetrating.
3. Such information as could be obtained from the history and from the general clinical picture.

If a positive diagnosis of a thoracoabdominal wound could not be made with reasonable promptness and the suspicion persisted that the diaphragm might have been perforated, prompt exploration was the rule. A positive preoperative diagnosis was naturally desirable, but if it could not be made, a reasonable suspicion that such an injury existed was sufficient indication for exploration. In many instances, a somewhat enlarged traumatic thoracotomy provided adequate exposure to determine whether or not the diaphragm had been perforated.

The only suspected thoracoabdominal injuries in which exploration was not regarded as mandatory were minor penetrations of the liver. If a foreign body was only 2 or 3 mm. in diameter, and if roentgenologic examination made it unmistakably clear that it lay entirely within the liver, expectant treatment was considered permissible in certain selected cases. Not more than 1 percent of all thoracoabdominal injuries fell into this category, and many surgeons considered the risk of biliary empyema too considerable to warrant expectant treatment in any case at all. Whenever the foreign body was over 3 mm. in diameter, regardless of its location, it was always best to determine surgically the exact damage that had occurred.

Negative Explorations

A rather large number of exploratory thoracotomies had to be performed because of the difficulty of making an accurate diagnosis of wounds around the diaphragmatic sulci. For this and other reasons, a significant number of negative explorations were carried out in all field hospitals. In the 2,267 penetrating and perforating wounds of the chest cared for by thoracic surgeons of the 2d Auxiliary Surgical Group, there were 903 proved thoracoabdominal injuries, almost 40 percent. Teams from this group, however, performed 122 exploratory thoracotomies in which no abdominal involvement had occurred.

These 122 negative explorations represent 28 percent of all thoracotomies done by these teams in forward hospitals.

To surgeons without experience in combat wounds, this figure may appear high. It is certainly high compared with the 41 explorations (1.3 percent) performed by surgical teams of the group in 3,154 abdominal wounds in which no intraperitoneal damage of any consequence was found (*1*). On the other hand, it is significant that well over half of these 41 negative explorations (28) were in thoracoabdominal wounds. In these 28 explorations, as in the 122 negative explorations performed for suspected thoracoabdominal wounds in this series of thoracic injuries, the indication was the same: Injuries of the abdominal viscera are so highly lethal if they are not treated surgically that no chance of overlooking them could be taken.

A practical consideration in the diagnosis of thoracoabdominal wounds was the echelon of medical care in which surgery was done. Casualties with thoracoabdominal wounds in which the diagnosis was clear cut were not transportable; surgery was done in field hospitals. Casualties in whom thoracoabdominal wounds were suspected also had to be cared for in field hospitals. Exploration could not be delayed until they reached an evacuation hospital.[2] If an abdominal injury were positively excluded, surgery for the chest injury could usually be deferred until an evacuation hospital was reached. Unnecessary exploration put an added strain on the space, facilities, and personnel of the field hospital, but it could not be omitted in any doubtful case.

RESUSCITATION AND PREOPERATIVE PREPARATION

General Considerations

Certain concessions to the realities of the situation had to be made in the resuscitation and preoperative preparation of casualties with thoracoabdominal injuries. The exigencies of the abdominal emergency were sometimes met at the expense of the most ideal preparation of the casualty from the point of view of cardiorespiratory stabilization.

From the standpoint of pure thoracic injuries, the length of time required, within reasonable limits, to restore thoracic casualties to as nearly normal status as possible before operation was not of primary importance. If the injury was limited to the thorax, the casualty frequently was benefited by a short period of stabilization after cardiorespiratory abnormalities had been corrected and shock controlled.

In casualties with thoracoabdominal wounds, the situation was entirely different. Time was of great importance. They had to be resuscitated as expeditiously as possible and operated on as soon as it was thought that they

[2] In certain military situations, evacuation hospitals served as the most forward hospitals in the area and acted in the capacity of field hospitals. In these circumstances, they operated on all nontransportable casualties.

could tolerate surgery. If a patient continued to have a low blood pressure, rapid pulse, and associated signs of shock after correction of the disordered thoracic physiology, supplemented by adequate replacement therapy, immediate surgery was indicated. Many patients who presented such a picture were found at operation to be bleeding seriously or to have massive pleural or peritoneal contamination from a perforated stomach or intestine. Their condition was frankly dangerous with immediate surgery, but entirely hopeless without it.

Patients with thoracoabdominal injuries were examined in the shock tent to determine their status in respect to shock and their cardiorespiratory status as manifested by respiratory restriction due to pain, embarrassment of respiration by hemothorax or pneumothorax, cyanosis, and excessive accumulations of blood and mucus in the tracheobronchial tree. In 669 thoracoabdominal injuries in the 2d Auxiliary Surgical Group records in which information is available on this point, 145 patients were not in shock but 75 were in mild shock, 174 were in moderate shock, and 275 were in severe shock.

Routine of Resuscitation

When thoracoabdominal casualties were received in the field hospital from the division clearing station, measures to combat shock and maintain respiratory equilibrium would already have been instituted. Sucking wounds of the chest would have been closed by occlusive dressings. Pain would have been relieved by morphine if it was indicated, or by intercostal nerve block. Plasma transfusions would also have been given as necessary. The 2d Auxiliary Surgical Group records in which information is available on this point show that 144 casualties had received no plasma, but 455 had received an average of 525 cc. each.

The records also indicate that while 60 casualties received no blood in the shock tent, 619 had an average of 1,100 cc. each. It is known that 252 casualties received no plasma in the shock tent and that 408 received an average of 500 cc. each. The usual practice was to begin the administration of plasma in the shock tent while waiting for blood to be crossmatched.

While plasma and blood were being administered, measures were instituted to correct the disordered cardiorespiratory physiology, including the administration of oxygen through a nasal catheter or mask (vol. I); intercostal nerve block if it had not already been carried out (vol. I); aspiration of air and blood from the pleural cavity (vol. I); and catheter or bronchoscopic aspiration of the tracheobronchial tree (p. 227). As a rule, the effect of these measures upon the cardiorespiratory imbalance and on the state of shock to which it was contributing was most gratifying.

As pointed out already (vol. I), a patient with a thoracic injury had to be treated judiciously in respect to replacement therapy because of the grave danger of overloading the already damaged cardiorespiratory system and pre-

cipitating pulmonary edema. The same precautions had to be observed in thoracoabdominal injuries. However much the casualty might need blood from the standpoint of the abdominal component of his wound, there was serious risk from the standpoint of the thoracic component in giving large amounts and in giving them too rapidly.

An important step in preoperative management was the introduction of a Levin tube, to aspirate the gastric contents and thus eliminate the risk of vomiting during surgery (vol. I).

It was a general policy to transport the patient from the shock tent to the operating table on the litter on which he had been placed originally, to operate on him on the same litter, and to move him to the recovery tent on it. Casualties with abdominal and thoracoabdominal wounds, particularly those who had been in serious shock, did not tolerate movement well, and this plan eliminated it while at the same time saving the time and effort of busy personnel.

Priority of Surgery

Unless severe intra-abdominal hemorrhage, which was not usual, demanded priority of treatment, the necessary intrathoracic surgery took precedence of the abdominal surgery. The importance of this sequence is evident in 15 deaths analyzed by Maj. (later Col.) Howard E. Snyder, MC, Consultant in Surgery, Fifth U.S. Army (*2*). In only one of seven cases in which laparotomy preceded chest surgery was there any indication for performing it first, and there seemed no doubt that the unwise order of precedence played a part in more than one of the fatalities.

ANESTHESIA

The anesthesia of choice in thoracoabdominal wounds was endotracheal ether and oxygen in a closed circuit, with induction by nitrous oxide and oxygen. In a small number of cases, Pentothal sodium (thiopental sodium) was used for this purpose. In 1942 and part of 1943, open drop ether was used in many operations because of the limited number of anesthetic machines. This technique was discarded as soon as these machines became generally available.

It was impossible to overemphasize the value of endotracheal anesthesia in thoracoabdominal surgery or of the services of an expert anesthesiologist. Such an anesthesiologist appreciated the value of frequent and thorough aspiration per catheter of the tracheobronchial tree throughout the operation; of bronchoscopy in selected cases at the end of operation; of replacement therapy during operation; and of positive pressure anesthesia when the thoracic cavity was open as well as during closure of the chest, when reexpansion of the lung was necessary.

Replacement therapy was carried out during surgery, the use of whole blood, plasma, or glucose or physiologic salt solution depending upon the needs of the individual patient. The records of the 2d Auxiliary Surgical Group that are complete in this respect show that 116 patients required no fluids on the operating table, 639 had an average of 1,000 cc. each of blood, 166 an average of 575 cc. each of plasma, and 78 an average of 1,000 cc. each of 5 percent glucose in physiologic salt solution in addition to the plasma and blood they received.

The casualties operated on by teams of the 2d Auxiliary Surgical Group were kept under anesthesia on an average of 2½ hours.

SURGICAL APPROACH

General Considerations

At the beginning of the fighting in North Africa, it was generally thought that the transdiaphragmatic approach to the abdominal component of thoracoabdominal wounds would be of only limited usefulness. At that time, and to a certain extent throughout the war, the decision as to the surgical approach depended not only upon the findings in the particular case but also upon the preference of the surgeon for the abdominal or thoracic approach. This preference usually depended, in turn, upon his experience, or lack of experience, in chest surgery. The experienced chest surgeon was able to select the single approach or the combined approach which best met the needs of the patient. Surgeons not widely versed in thoracic surgery found it safer to repair the intraperitoneal damage through a laparotomy incision after handling the thoracic damage and closing the diaphragm through the chest.

By the end of the war, it was the opinion in the Mediterranean theater—an opinion shared by the more experienced of the thoracic surgeons in the European theater—that whenever it was practical, thoracotomy with transdiaphragmatic repair of all accessible abdominal injuries was infinitely the procedure of choice. If total repair was not possible by the transthoracic approach, the best plan in left-sided wounds was to correct the intrathoracic damage, care for any damage readily accessible in the left upper quadrant of the abdomen, close the diaphragm, reexpand the lung, close the chest wall tightly, and then proceed with the repair of intraperitoneal injuries not accessible through the diaphragm. The same general principle was applicable to wounds of the upper right quadrant of the abdomen, but the extent of surgery possible in this quadrant was, for anatomic reasons, much less than on the left side.

When the thoracic and abdominal wounds were separate, transdiaphragmatic surgery was not indicated because it subjected the pleura to contamination which did not already exist. In these cases, the chest wound was given priority unless profuse intra-abdominal bleeding or massive evisceration made laparotomy necessary as the primary procedure.

Advantages and Disadvantages of the Transthoracic Approach

No hard-and-fast rule, covering all casualties, could be laid down for the approach to a thoracoabdominal wound. There were advantages and disadvantages to both the thoracic and the abdominal approaches, and each casualty had to be individualized.

In favor of the transthoracic approach were the following arguments:

1. If there was extensive thoracic damage, the chest injuries could not be repaired from below the diaphragm.

2. Certain wounds of the upper abdomen were more easily handled through the diaphragm than through a laparotomy incision. These included wounds of the spleen, the dome of the liver, both kidneys, the upper portion of the stomach (especially if the posterior surface was injured), and the splenic flexure of the colon. There was real danger of overlooking wounds of the posterior wall of the stomach and of the retroperitoneal portion of the splenic flexure, as well as wounds of certain areas of the spleen, when the approach was by laparotomy.

3. Injuries of the diaphragm, whether on the right or the left side, especially if they were extensive, were more readily repaired transthoracically. If the wound was small, it could as well be repaired from below as from above. Injuries over the dome of the liver, however, as well as such large defects as resulted from tearing of the diaphragm from the costal margin, especially posteriorly, were much more readily repaired from above.

4. The transthoracic approach permitted exteriorization of the transverse or splenic flexure of the colon through a subcostal gridiron incision at a greater distance from the surgical incision than was possible if laparotomy had been done. Wound infection was thus reduced to a minimum.

5. If considerable pleural contamination had occurred from spillage of gastric or intestinal contents, it could be reduced by copious pleural lavage with physiologic salt solution, a procedure possible only through the chest.

6. There was no validity to the objection, sometimes raised, that wounds of the gastrointestinal tract should not be dealt with through the chest because infection of the pleural cavity might result. For one thing, considerable damage to the intrathoracic organs might exist without being evident before the chest was explored. For another, potential infection existed whenever the diaphragm had been perforated by the missile. If hollow organs in the abdomen had been perforated, feces and gastric contents had been sucked into the pleural cavity before the surgeon ever saw the casualty.

7. If the chest was long and narrow, with an acute angle at the costal arch, subdiaphragmatic repair was often technically very difficult.

8. Blockage of the intercostal nerves, for anatomic reasons, was much easier when the transthoracic approach was used. These nerves lie underneath the ribs and course downward diagonally to supply the upper abdomen. When they were blocked at operation, both thoracic and abdominal pain was decreased. As a result, after operation, the patient coughed willingly, and as

a further result, the lungs were more adequately aerated and bronchial secretions were raised more completely.

9. Since abdominal relaxation was not necessary when the transthoracic approach was used, the patient could be carried in a lighter plane of anesthesia.

10. If the transthoracic approach revealed intra-abdominal injuries that could not be repaired from above, it was a simple matter to perform the necessary chest surgery, close the diaphragm and chest wall, and then perform the necessary intraperitoneal surgery through a separate laparotomy incision. As already emphasized (p. 113), in the absence of compelling reasons for reversing the order, chest surgery was always done first, in order to restore normal cardiorespiratory conditions as promptly as possible.

Against these multiple advantages of the transthoracic approach were the following arguments for repair of intraperitoneal damage through a laparotomy incision:

1. Certain wounds of the small bowel and colon could not be exposed adequately through the diaphragm and had to be repaired by laparotomy. These included wounds of the terminal 18 inches of the small intestine and all wounds of the colon except wounds of the transverse portion, the splenic flexure, and the proximal portion of the descending colon.

2. When thoracic damage was minimal, an abdominal approach avoided unnecessary entrance into the pleural cavity. This was not a sound argument. When the abdomen was opened, all but the most minimal perforations of the diaphragm constituted, in effect, sucking wounds, which carried all the risks of sucking wounds of the chest wall (p. 105). Not infrequently, patients developed pulmonary embarrassment while the abdominal repair was in process because of aspiration of air into the chest through the diaphragmatic opening. If the situation was unrecognized and uncorrected, serious results could follow, including aspiration into the pleural cavity of intestinal and gastric contents free in the peritoneal cavity. If the abdominal approach was used, repair of the diaphragm was necessarily the first step of the procedure, to avoid these dangers, instead of the last before wound closure, as in the transthoracic approach.

INCISION

Four types of incisions, in addition to separate thoracic and abdominal incisions, were employed in thoracoabdominal wounds:

1. Limited thoracotomy, accomplished by an extension of the original wound (traumatic thoracotomy). This was often a satisfactory incision when injuries were confined to the chest. It was not usually satisfactory in thoracoabdominal wounds unless the original injury in the chest wall was large enough to supply adequate exposure, which was essential for exploration of the upper abdomen and repair of damaged intra-abdominal viscera. If the original wound was below the tenth rib, and especially if the missile had gone through the eleventh or the twelfth rib, traumatic thoracotomy was entirely

impractical. Even resection of one or more ribs did not provide satisfactory space for maneuvers. Wide exposure was essential. If there was any reason for inspection of the interior of the thorax, there was every reason for adequate investigation.

2. Thoracotomy in the area of the original wound.

3. Thoracotomy outside the area of the original wound. The majority of thoracotomies fell into either this group or the second group. The formal approach was usually posterolateral and usually through the ninth intercostal space or the bed of the ninth rib. Injuries of the mid or anterior portions of the diaphragm were often approached through the eighth interspace or the bed of the eighth rib. A small number of thoracotomies were performed laterally, in the region of the sixth or seventh ribs, more often through the intercostal spaces than through the bed of the ribs. It was always best, if it was anatomically feasible for good exposure, to resect a rib that was not involved in the wound of entrance or exit, in order to reduce the chances of postoperative wound infection with involvement of the diaphragm.

4. Thoracolaparotomy, an incision in which the thoracic incision was extended through the costal arch onto the abdomen. This was not a popular incision because of the resulting instability of the chest wall and the increased morbidity if infection occurred in the costal cartilages. It was used only six times in the 903 thoracoabdominal wounds cared for by the 2d Auxiliary Surgical Group. In two of these injuries, the rib margins had been destroyed by the original wounds, and this approach was used as a matter of expediency. In one of the four other cases, in all of which the incision was elective, the wound broke down and the resulting infection was fatal. Most chest surgeons believed there was nothing to be said in favor of this approach as an elective procedure.[3]

TECHNIQUE

Management of the Thoracic Component

The thoracic component of the thoracoabdominal wound was treated in much the same manner as if it were the only wound. The principal difference was that, because of the abdominal element and the transthoracic approach, many chest wounds were treated by thoracotomy in field hospitals that otherwise would have been treated in evacuation hospitals and only by debridement and thoracentesis. Once the thoracic cavity was entered, there would have been no point to not removing intrapulmonary foreign bodies and bone fragments, though a prolonged search for small missiles was not warranted. Pulmonary lacerations of more than 4 or 5 cm., as well as any lacerations which demonstrably leaked air, were repaired with interrupted sutures.

[3] The long vertical abdominal incision introduced by Duval in World War I does not seem to have been employed in World War II. It was used by Wangensteen after World War I, and it was employed by Norwegian surgeons in a forward hospital during the Korean War.—F. B. B.

Management of the Abdominal Component

Standard practices were also followed in the management of the abdominal component of the wound. In brief, wounds of the stomach were sutured. Wounds of the small intestine were treated by suture or by resection and anastomosis, according to the indications. Wounds of the colon were exteriorized or managed by colostomy. Wounds of the spleen were treated by splenectomy. Wounds of the pancreas were treated by suture and drainage or by drainage alone. Wounds of the kidney were preferably treated by drainage; nephrectomy was performed only when the pelvis was definitely involved or when hemorrhage was intractable. The management of all of these wounds is described in detail in the volume on general surgery devoted to abdominal injuries (*1*).

Wounds of the liver.—Wounds of the liver require special mention. Even if only a small fragment had penetrated the liver substance, it was conservative management to explore the wound, since it was not possible to determine from the size of the missile the precise site of the diaphragmatic laceration or the extent of hepatic damage. In some instances, particularly when a rib had been fragmented, a surprising amount of diaphragmatic and hepatic damage was caused by the passage of a small missile.

Experience in World War II soon showed that any wound of the liver that warranted exploration also required drainage. A wound too small to demand drainage was almost never encountered. It is quite true that bile did not drain after operation in some cases, but there were no criteria by which the injuries in which this would happen could be identified at operation. The size of the missile was not the deciding factor. If a small missile cut across a main bile passage, drainage was more profuse than it might be after a more superficial hepatic wound of greater extent. The larger bile radicles were frequently involved in wounds that looked innocent.

If drainage was omitted and infection developed, the resulting draining sinus often took weeks to close. In other cases, the diaphragmatic repair broke down, particularly if the perforation was over the bare area of the liver over which there is no peritoneum. The pooled blood and necrotic material from the damaged liver readily broke through the unfortified diaphragmatic suture line. The resulting biliary pleural fistulas were difficult to treat, and there was more than a casual relation between them and pleural empyemas.

The use of gauze packs was abandoned early in the war as both inefficient and hazardous. They gave rise to subphrenic, subhepatic, or pelvic collections of bile, often with associated abscess formation. Since the diaphragm was perforated in all thoracoabdominal wounds, bile and exuded fluids, whose external discharge was prevented by the pack in the liver, tended to force their way through the sutured diaphragmatic wound, no matter what the technique of suture, with resulting biliary fistulas and bile empyemas. In some instances, the thoracotomy incision broke down, and pleurocutaneous fistulas developed.

In two cases, in which the lung was adherent to the suture line in the diaphragm, a serious problem was created when the bile eroded into a bronchus.

Other disadvantages connected with the use of gauze packs concerned their removal, which was usually painful and was often followed by secondary hemorrhage. In one such case in the experience of the 2d Auxiliary Surgical Group, the granulation tissue that had invaded the meshes of the gauze bled so profusely when the pack was removed that the patient was exsanguinated before surgical intervention could be undertaken. Autopsy showed vascularization of the liver bed as a reaction to the presence of the pack.

Complications associated with the use of gauze packs were so numerous and so troublesome that their use was eventually discontinued, and Penrose drains were substituted for them. These drains, however, were satisfactory only when the drainage incision was of adequate size not only on the surface but through all layers of the drainage tract. It was also essential that they be placed under direct vision when the abdomen was still open.

Adequate drainage implied the proper placing of two or three large, soft rubber drains to the site of the liver damage through an adequate anterolateral subcostal incision. The incision was not adequate unless it was at least 3 inches long. A tract was established extraperitoneally by blunt dissection until the upper surface of the liver was reached; then the peritoneum was broken through. The drains were placed precisely, under direct vision, before the diaphragm was closed. Often both anterior and posterior drainage was desirable. Drains to the liver were never brought to the surface through the thoracotomy incision or the laparotomy incision. This would have been an invitation to wound infection and disruption.

There was a significant reduction in the complications caused by inadequate drainage of wounds of the liver as the principles of drainage became more clearly understood and the proper techniques were put into effect. Constant emphasis upon both principles and practices was, however, necessary throughout the war.

Closure of the Diaphragm

The rent in the diaphragm was repaired as securely as possible to forestall the development of bile empyema on the right side and of diaphragmatic hernias, which were more of a threat on the left than on the right side. When thoracotomy and laparotomy had been done as separate procedures, the diaphragm was preferably repaired from above, through the thoracotomy. Closure from below was much more difficult and much less satisfactory.

The anesthesiologist had much to do with the ease with which the diaphragm was closed. If he initiated a period of controlled respiration, thus securing complete diaphragmatic relaxation and immobility, closure was greatly facilitated. Relaxation was particularly important when the closure had to be effected in a site that would not have been the site of election: in war wounds, the surgeon had no choice.

Several techniques were used to close the diaphragm, a 2-layer closure being generally regarded as most satisfactory. It was accomplished either by imbrication of 2 cm. of diaphragmatic tissue or by simple approximation of the wound edges, reinforced by a second layer of inverting mattress sutures. Neither of these techniques was practical through an abdominal approach.

Crushing of the phrenic nerve was practiced only when there had been actual loss of muscle tissue, so that closure under tension would otherwise be necessary.

Silk or cotton sutures were used, sometimes combined with chromic catgut. Silk was used in 373 of the 636 cases in which 2d Auxiliary Surgical Group records have information on this point. Sutures were always interrupted.

Special techniques were necessary for special wounds. An apparent defect in the lateral costal margin of the diaphragm, which was the result of contraction or avulsion after severance of its attachments, was corrected by suturing the diaphragm to an intercostal muscle one or more spaces higher than its original attachment. Reattachment was important, for the original site of attachment was usually in the area of the chest wall wound, with its accompanying fractures, and this structure was no longer stable enough to permit efficient diaphragmatic action.

When the diaphragmatic crura had been torn from the vertebral column, the first layer of sutures had to be passed through the superior surface of the liver. A sufficient number of these sutures always held to fix the liver against the undersurface of the diaphragm and thus prevent herniation.

Pleural Lavage

Before the chest wall was closed, all blood was suctioned out of the hemithorax, and it was adequately flushed with physiologic salt solution (vol. I). This measure was particularly important if there had been soiling of the cavity by gastric or intestinal contents.

Drainage

Whether to institute drainage of the pleural space at operation or to rely upon keeping it empty after operation by thoracentesis was a matter of prime importance in securing reexpansion of the lung. The decision depended upon a number of considerations, including the extent of pulmonary damage; the magnitude of the laceration in the diaphragm; the size of the defect in the chest wall; and, most important, whether or not the pleura had been grossly contaminated through the diaphragm from a perforated abdominal viscus.

Unless the defect in the thoracic wall was small, pulmonary and diaphragmatic injuries minimal, and gross contamination of the pleural and peritoneal cavities absent, it was not safe to omit water-seal intercostal drainage and to rely upon postoperative thoracentesis to keep the pleural cavity free of blood and air. When water-seal drainage was employed, the chances of pleural

infection were reduced, and, if it did occur, the process was limited and localized because there was no pleural dead space.

According to the records, closed water-trap intercostal drainage was instituted in 326 of the 903 thoracoabdominal injuries cared for by teams of the 2d Auxiliary Surgical Group. The practice was to use either a large fenestrated catheter or a tube of equal caliber; both were rigid enough not to collapse. The site of drainage was a separate intercostal stab wound, usually in the posterolateral or lateral aspect of the lower chest. A small additional catheter was sometimes placed in the second interspace anteriorly, for the escape of air trapped in the upper pleural cavity.

Closure of the Chest Wall

Closure of the thoracic cage was accomplished by approximation of adjacent ribs or of the intercostal musculature, depending upon whether thoracotomy had been performed through the bed of a rib or through an intercostal space. If there were large defects in the thoracic wall, contiguous musculature was utilized in layers. In closing the posterior aspect of the pleural incision, it was often useful to pull the paraspinalis muscle over the suture line for additional reinforcement. The muscular layer was always closed, but the subcutaneous tissue and skin were usually left open for subsequent closure.

SPECIAL SURGICAL CONSIDERATIONS

Special surgical conditions in the management of thoracoabdominal wounds depended upon (1) which side they were located, and (2) whether they were penetrating or perforating.

Right-Sided Wounds

Perforating wounds.—When the wound on the right side was low in the costal margin or in the region of the tenth, eleventh, or twelfth ribs posteriorly, possible injury of the gallbladder, liver, duodenum, colon, and kidney had to be borne in mind. Exploration by the transdiaphragmatic route was often not satisfactory in injuries in these locations because the liver blocked vision and prevented adequate exploration.

Debridement of the wounds of entrance and exit and investigation of the status of the diaphragm through a traumatic thoracotomy sometimes revealed that only the diaphragm and liver, or sometimes the kidney, had been damaged. If the thoracotomy was as low as the tenth interspace posteriorly, the liver could be drained or the kidney sutured or removed through the diaphragm.

Wounds of the diaphragm no higher than the eighth interspace and no farther posterior than the posterior axillary line could be exposed and sutured from within the abdomen. The condition of the patient determined whether lacerations of the diaphragm in other areas should be repaired at this time.

Failure to repair a laceration of the diaphragm might lead to a biliary pleural fistula, but the possibility of this complication was not of major importance in a patient in such poor condition that he could not tolerate further surgery.

Early surgical intervention was imperative when the right lobe of the liver continued to bleed into the pleural cavity or when the spleen lay shattered in the left pleural cavity. The situation was evaluated on the basis of the location of the wound of entry, the position of the fragment, and the lack of response to shock therapy. It was often necessary to operate without delay in spite of persistent hypotension.

It was also possible to drain a wound of the liver through a traumatic thoracotomy in this location. The most satisfactory plan was to lay Penrose drains over the rent in the liver and exteriorize them subcostally by breaking through the lateral reflection of peritoneum over the right lobe. Whatever the technique used, drainage was essential.

When there was no urgent indication for laparotomy before thoracotomy, the first attention was given to the chest wound. After debridement, closure of the chest wall, insertion of an intercostal tube, and aspiration of all blood and air in the pleural cavity, it was surprising to find how often the patient's condition had improved and how much better he tolerated extensive intra-abdominal surgery. The intercostal tube was drained into a water-trap bottle, and it was thus possible to check on the amount of hepatic bleeding. The drainage of blood into the pleural cavity, which would otherwise have occurred, might have considerably lowered the already impaired vital capacity by the time laparotomy was concluded.

An extrapleural approach was used in an occasional thoracoabdominal injury low on the right side posteriorly, but only if the thoracic injury was not severe and if it was quite certain that the liver was the only abdominal organ injured. The eleventh or twelfth rib was resected, and the reflection of the pleura was dissected up. The pleural defect, being thus exposed, was then repaired, after which the liver was approached either through the perforation in the diaphragm made by the missile or through the bed of the resected rib. The operation was performed exactly as drainage for a subphrenic abscess would be instituted. In selected cases, this was a safe and simple way of draining wounds of the liver.

Penetrating wounds.—When a penetrating wound was on the right side, it was necessary to investigate whether the missile had passed through the right lobe of the liver or had entered the peritoneal cavity. As a general rule, the laparotomy approach was best when roentgenologic examination showed the missile to be in the peritoneal cavity. If roentgenologic examination indicated that it had stopped in the liver, the procedure was the same as for right-sided perforating wounds; that is, drainage of the suprahepatic space and repair of the diaphragm. If the fragment was readily accessible, it was removed, but protracted exploration for a buried intrahepatic foreign body was not wise, for it often resulted in considerable hemorrhage. Drainage, as al-

ready pointed out (p. 118), was mandatory to guard against subphrenic space infection and bile empyema.

Left-Sided Wounds

Perforating wounds.—Possible injury to the left diaphragm was always in itself a sufficient indication for thoracotomy. It was a simple matter, in the process of handling a sucking wound, to enlarge the wound and determine the status of the diaphragm. Since the chest wall is relatively thin in the lower thoracic cage, most wounds were sucking.

Penetrating wounds.—Accurate localization of the missile was important in left-sided penetrating wounds in order to determine the surgical approach. Any damage done to intraperitoneal organs by a missile that entered the left upper quadrant of the abdomen and remained in it could easily be reached and remedied through a transdiaphragmatic approach, with greater technical ease, in fact, than was possible at laparotomy. If, however, the missile had passed into any other quadrant of the abdomen, laparotomy was necessary.

The left transdiaphragmatic approach had many technical advantages. Through it the following procedures (fig. 37) were readily performed: Splenectomy; exploration and repair of the entire stomach from the esophagogastric junction to the duodenum; examination and mobilization of the colon from the hepatic flexure to the first portion of the sigmoid loop; examination of the hepatic flexure itself, by blindly taking down the hepatocolic ligament; repair of the colon, or subcostal or midline exteriorization of either loop, or spur colostomy; examination of the small bowel from the ligament of Treitz to within a few inches of the cecum, with resection or anastomosis as necessary; and visualization and removal of the left kidney.

The abdominal approach was required for repair of wounds of the lower ileum and cecum and of wounds of the colon from the hepatic flexure to the upper sigmoid. These structures could not be adequately exposed through the diaphragm.

The abdominal approach was also wisest when thoracic damage was so slight that no intrathoracic surgery was necessary. If the diaphragm could be repaired from below in these cases, it was best not to enter another serous cavity.

When the foreign body was in the left upper quadrant of the abdomen and the wound of entrance was not sucking because the missile had traversed the chest wall obliquely, it could be assumed that pleural contamination had not occurred. The decision then had to be made whether to perform laparotomy or to employ a transthoracic approach, with the possible risk of pleural contamination. Many surgeons, on the basis of their personal experience, thought the minimal risk justified because of the greater technical ease of repair of intraperitoneal structures through this approach. The chances of infection were small with an experienced surgeon, who bore in mind the importance of

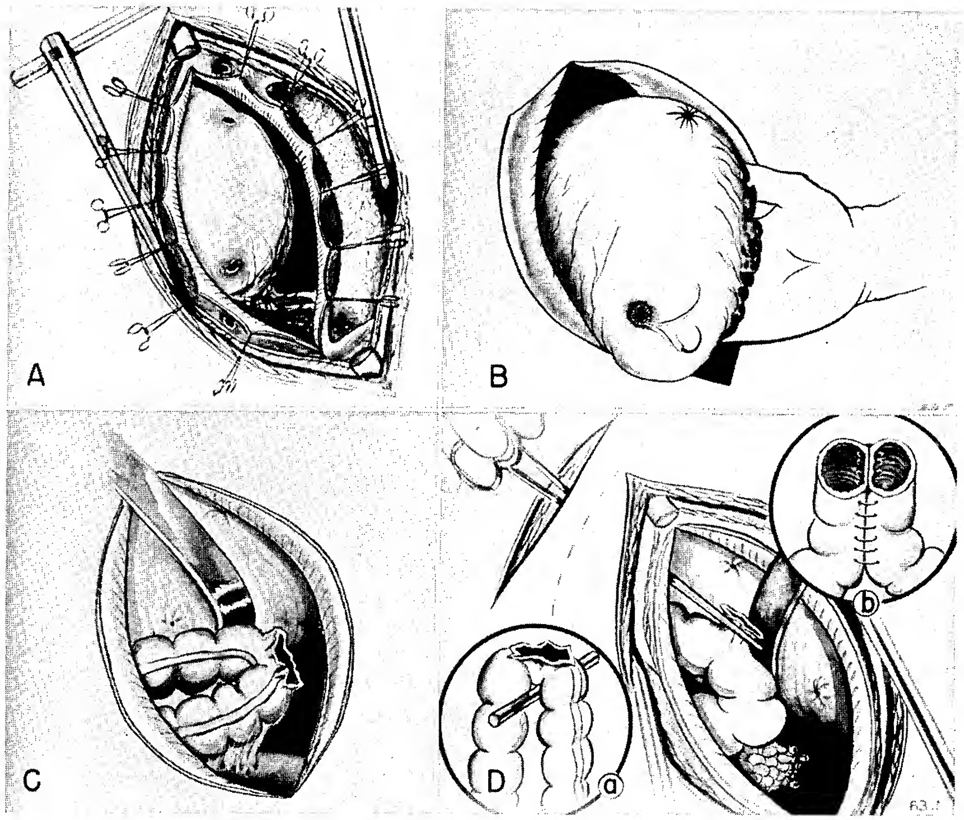

FIGURE 37.—Technique of transdiaphragmatic operation for left-sided thoracoabdominal wound. A. Exposure of gastric perforations after excision of ninth rib and opening of diaphragm. B. Field after splenectomy and closure of gastric perforations. C. Large laceration in splenic flexure of colon. D. Subcostal exteriorization of splenic flexure as loop (a), or spur colostomy (b). In general, spur colostomy was indicated when more than half of the diameter of the bowel had been transected or when the wound was on the mesenteric side and the blood supply was questionable.

a fully expanded lung, a dry pleural cavity, and proper attention to pleural lavage and pulmonary expansion during closure of the thoracotomy.

The following technique for left-sided thoracoabdominal wounds was reported by Major Shefts and Captain Doud:

After the patient had been anesthetized, he was placed on his right side, with a folded blanket under the lower lateral aspect of the right costal margin. A long strip of adhesive placed over the left hip and attached to the litter anteriorly and posteriorly helped to hold the position. The left leg was flexed at the hip and knee, and a pillow was placed below the knee. With the right leg extended, the great saphenous vein anterior to the medial malleolus or at the middle border of the tibia was available if the administration of fluids during the operation should prove necessary.

The rib chosen for resection varied with the habitus of the patient and could be determined during debridement of the wound. The best approach was usually through the bed of the resected ninth rib. Resection stopped short of the costal cartilage, to prevent the chondritis possible if contamination should have occurred. When the diaphragm was opened, the perforating wound was included in the incision whenever that was possible.

When it was necessary to explore the stomach, access to the posterior wall was obtained by opening the gastrocolic omentum. For exposure of injuries in the region of the esophagogastric junction, especially those on the side of the lesser curvature, it was necessary to cut the left triangular ligament and mobilize the left lobe of the liver.

When splenectomy was indicated, the lateral reflection of peritoneum over the spleen was cut and the spleen delivered into the opening in the diaphragm. The operation was technically easier if, after the spleen had been delivered, the surgeon and his assistant changed sides. The assistant maintained the spleen in position with his left hand, while the surgeon passed his fingers beneath the splenic pedicle. With this maneuver, the risk of injury to the greater curvature of the stomach and the tail of the pancreas was greatly decreased.

To expose the left kidney, the lateral peritoneal reflection of the upper portion of the descending colon was cut, together with the lienocolic ligament, and the colon was retracted mesially. Nephrectomy was readily performed through this approach.

POSTOPERATIVE CARE

In general, the postoperative care of the casualty with a thoracoabdominal wound consisted of the care that would be given to him if he had a chest wound only (vol. I) plus the management of an abdominal wound only. The routine of the postoperative care of casualties with abdominal wounds is described in detail in the volume of this series dealing with these wounds (*1*) and need not be repeated here.

As a general rule, the absence of an abdominal incision made for a smoother convalescence because abdominal discomfort and distention were less. Since he was more comfortable, the patient was likely to be more willing to cooperate in the measures necessary for promoting pulmonary expansion and keeping the tracheobronchial tree clear.

Routine of Management

Measures directed to the respiratory system.—Before a patient with a thoracoabdominal wound was removed from the operating table, the tracheobronchial tree had been cleared by aspiration or, if necessary, by bronchoscopy. Bronchoscopy was employed in 110 of the 903 thoracoabdominal operations done by surgeons of the 2d Auxiliary Surgical Group. If the patient showed any cyanosis or respiratory difficulty, oxygen was administered at once.

As soon as the patient was conscious, he was given instructions for deep breathing, frequent coughing, and turning from side to side. If he could not or would not cough voluntarily, intercostal nerve block was carried out if it had been omitted at operation.

Tracheal aspiration by catheter was also begun and was repeated as frequently as necessary as long as there were detectable amounts of blood or mucus in the tracheobronchial tree. Often after the first tracheal aspiration, the patient coughed voluntarily and without protest and kept the air passages clear by his own efforts. If he could not or would not cooperate, or if catheter aspiration was unsatisfactory, bronchoscopy was resorted to promptly. It was performed after operation in 12 of the 903 thoracoabdominal wounds cared for by members of the 2d Auxiliary Surgical Group. Atropine gr. 1/100 was given intravenously from 10 to 15 minutes before it was begun, to eliminate the risk of vagovagal reflex. Bronchoscopy could be performed quickly and easily on the ward because most members of thoracic surgical teams—surgeons, assistant surgeons, and anesthesiologists—were all trained to perform it.

If the ward was busy and repeated observation was not practical, it was the best plan to use an oral or nasal airway to maintain patency of the respiratory passages. At least one thoracoabdominal casualty is known to have died of strangulation 3 hours after operation because this precaution was omitted on a busy postoperative ward.

Replacement therapy.—Replacement therapy was continued after operation according to the indications. The amount of blood and plasma administered depended upon the hemoglobin, hematocrit, and serum protein determinations. Between 2,000 and 3,000 cc. of 5 percent glucose in physiologic salt solution was given daily. This amount was not usually exceeded because it was still possible to overload the circulation and produce pulmonary edema.

Gastrointestinal decompression.—All patients with thoracoabdominal wounds were treated by nasal intubation and gastric siphonage for 3 or 4 days after operation, the removal of the tube depending upon the time at which satisfactory peristalsis was reestablished. The use of the tube beyond this period was undesirable, for it might mask an intestinal obstruction and delay its recognition and correction. An accurate record of the daily intake and output was necessary during the period in which nasogastric suction was in use.

General measures.—If morphine was indicated for pain, it was given in small doses, preferably gr. 1/6 and never more than gr. 1/4.

Patients were encouraged to get out of bed promptly if other wounds did not contraindicate ambulation. If drainage had been instituted, ambulation usually had to be delayed until the water-seal catheter was removed, but these patients were encouraged to sit on the side of their beds.

The sulfonamides and penicillin were used according to the routine described for thoracic wounds (vol. I).

Vitamins B and C were given routinely in the postoperative period to improve the nutritional status.

The roentgenograms ordinarily taken in chest injuries 4 or 5 days after operation were usually deferred until after the first week in thoracoabdominal wounds. Clinical signs provided a satisfactory guide to management.

Drainage

The care of water-trap drainage in the postoperative period required constant vigilance on the part of the surgeon and a thorough knowledge of the method plus conscientious attention on the part of the nursing and other staff members of the forward hospital. Serious errors might result when untrained personnel were entrusted with this phase of the patient's care.

The catheter was connected with the water-seal bottle as soon as the patient was returned to the ward. If two tubes were used and penicillin had been left in the pleural cavity, the posterolateral tube was kept clamped for 3 to 4 hours, to give the penicillin time for bacteriostatic action. The patient was watched closely and the tube was unclamped immediately if pneumothorax or hemothorax seemed to be developing.

The water-seal bottle was kept at least 18 inches below the most dependent part of the pleura. The tube was clamped off whenever the bottle had to be emptied. It was the general practice to continue water-trap intercostal tube drainage for 48 to 72 hours unless the tube became sealed off earlier; this sometimes occurred within 24 hours.

After the tube had been removed, and earlier if drainage had not been instituted, aspiration of blood and air from the chest was carried out as indicated. Daily aspirations were sometimes necessary. Often a pocket of air was evident anteriorly, even when drainage had been instituted by lateral or posterolateral intercostal drainage. It was aspirated at once.

The proper removal of drains down to the liver was as important as their initial placement. They were gradually shortened, usually beginning on the fourth or fifth day. Manipulations had to be cautious and gentle. If the drains were withdrawn too far and too fast, fluid collections were likely to become pocketed in the hepatic region.

The amount of drainage through tubes placed down to the liver was generally, though not always, related to the amount of hepatic damage. The period of drainage was unpredictable, but it was seldom shorter than from 10 to 12 days, which meant that the final removal of drainage tubes was usually the responsibility of the surgeon in the base hospital.

MANAGEMENT IN BASE HOSPITALS

Of the patients who survived to reach base hospitals after surgery for thoracoabdominal wounds, about half would have had involvement on the left side and would have undergone, variously, splenectomy; repair of gastric lacerations; exteriorization of a segment of the colon, usually the splenic flexure

or descending colon; nephrectomy in a small number of cases; or various combinations of these procedures.

Of the patients with right-sided injuries, the majority would have had injuries of the liver as the only intraperitoneal injury. The remaining patients with injuries on this side would have had thoracotomy with inspection of the abdomen, repair of the diaphragm, and laparotomy to deal with injuries inaccessible from the right hemithorax.

Except for the closure of traumatic wounds and of elective incisions in which the skin and subcutaneous tissues had been left open, the chief responsibility of surgeons in base hospitals in respect to thoracoabdominal wounds was the management, and sometimes the closure, of colostomies and the management of complications.

Management of Colostomies

The management of colostomies in thoracoabdominal injuries was the responsibility of general surgeons in base hospitals. In many cases, perhaps most cases, the patient had recovered entirely from his chest injuries long before the closure of his colostomy was undertaken. Many patients with thoracoabdominal injuries had to be evacuated to the Zone of Interior because the colostomy could not be closed within the permitted holding period of the theater or because, for other reasons, closure could not be attempted overseas.

There was no standard surgical technique for the management of wounds of the colon in the Mediterranean theater, but all the techniques employed were based on three general principles (*1*):

1. Exteriorization of the wounded segment of bowel to prevent intraperitoneal leakage at the suture line. The damaged exteriorized segment could be used as the site of colostomy on appropriate indications.

2. Diversion of the fecal stream away from wounds of the distal or lower colon and rectum. Colostomy was always performed for perforation of the rectum and was supplemented by adequate posterior drainage through the fascia propria.

3. Incomplete diversion of the fecal stream, which was a temporary measure, designed for purposes of decompression as well as to bring the bowel to the surface, so that a diversional colostomy could be performed.

As might be expected, when so many different surgeons had operated on so many patients under such widely different circumstances, with only principles to guide them, the colostomies that had to be closed represented every known technique. Closure therefore had to be accomplished by a corresponding variety of techniques. Both intraperitoneal and extraperitoneal methods were found satisfactory. Careful preoperative preparation was a criterion of success.

Techniques of the closure of colostomies and the management of complications associated with them are presented in detail in the volume on general surgery devoted to abdominal injuries (*1*).

Complications

As might be expected in the circumstances of war, the records of complications of wounds were always incomplete and were particularly fragmentary in respect to the less severe and nonfatal types. Many postoperative processes which in civilian practice would be regarded as complications were so frequent in battle wounds that they came to be accepted as routine and were not made a matter of record.

These statements are all applicable to the 903 thoracoabdominal wounds cared for by the 2d Auxiliary Surgical Group. In 529 instances, the records bear no indication that complications occurred, which naturally is incredible. There is only one recorded case, for instance, of postoperative pulmonary edema. The largest numbers of complications were recorded for atelectasis, 21 cases; empyema, 19 cases, 2 of which where associated with bronchopleural fistula; subphrenic abscess, 15 cases; and pneumonia, 12 cases. Ten disruptions of the abdominal wound were recorded, in three instances with evisceration.

Postoperative complications were remarkably few, considering the character of the wounds, but individual surgical experiences often included more than these presumably total figures indicate. Maj. Thomas H. Burford, MC, for instance, in 98 lacerations of the liver treated at base hospitals, collected 14 subphrenic abscesses (fig. 38), 5 bile empyemas, and 6 intrahepatic abscesses (fig. 39).

Right-sided thoracoabdominal injuries gave rise to a higher percentage of complications than left-sided injuries because of the almost universal involvement of the liver on this side. It was estimated that transdiaphragmatic biliary fistulas, with bile empyema, developed in about 3 percent of the lacerations of the liver in right-sided wounds. The incidence of hepatic abscesses was put at about 1 percent.

Almost without exception, patients with left-sided injuries did well if they survived the first week. Complications arising within the abdomen were significantly less than on the right side, though an occasional left-sided subphrenic abscess required drainage.

Bile empyema.—Bile empyema resulting from the intrapleural, transdiaphragmatic drainage of bile was always serious. The complication was not usually lethal, but it invariably showed a troublesome predilection toward chronicity, which was attributed to the presence of bile in the pleural cavity.

Attempts at decortication of the lung, with excision of the fistula and tight diaphragmatic repair, failed consistently when they were undertaken as late as 6 or 8 weeks after injury. At this stage, it seemed impossible to achieve complete pulmonary remobilization and total pulmonary reexpansion. On the other hand, early surgical attack, within 3 or 4 weeks after injury, gave gratifying results (p. 130). An important phase of the operation was the provision of adequate extrapleural, extraperitoneal drainage for the bile leakage. This was accomplished by placing the rubber tissue drains exactly at the point of

FIGURE 38.—Thoracoabdominal wound requiring later drainage of anterior subphrenic abscess following laceration of liver.

hepatic injury while the diaphragm was still open and bringing them out through a generous subcostal wound.

Subphrenic abscess.—Subphrenic abscesses were almost universally of the anterior type and most frequently developed from an inadequately drained transdiaphragmatic abscess of the liver (fig. 40). They were treated by adequate drainage, which occasionally necessitated resection of a segment of the tenth rib below the pleural reflection. Most patients showed satisfactory progress toward healing of the underlying biliary fistula by the time they were evacuated to the Zone of Interior. In one instance, a left-sided subphrenic abscess ruptured through into the left lower lobe bronchus. Adequate drainage below the diaphragm resulted in prompt and complete cure.

In an occasional case, a bile empyema and a subphrenic abscess coexisted:

Case 1.—This patient sustained a penetrating shell-fragment wound of the right chest on 14 April 1945. Exploratory thoracotomy on the same day revealed a penetrating wound of the right half of the diaphragm and a laceration of the liver. Subcostal drainage was instituted, and the diaphragm was closed with interrupted cotton sutures. The immediate postoperative course was uneventful. The subcostal drains were loosened on the fourth postoperative day and removed on the seventh day.

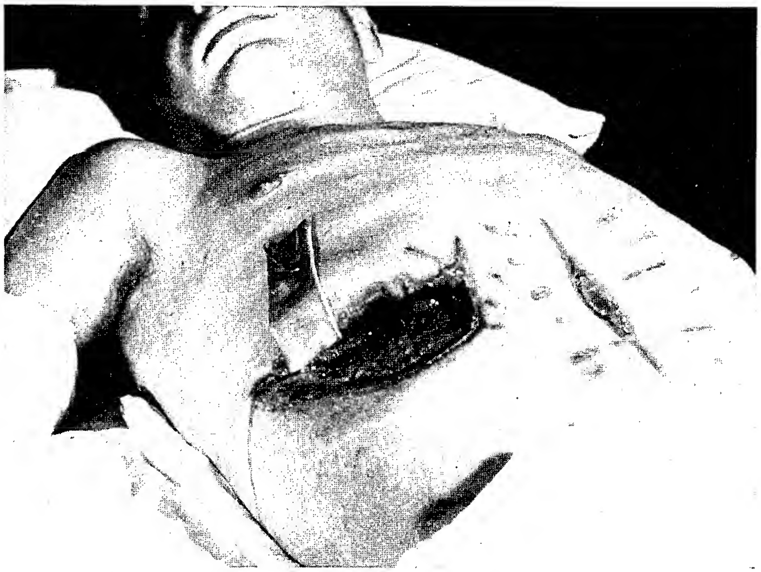

FIGURE 39.—Thoracoabdominal wound requiring later drainage of large intrahepatic abscess.

When the patient was received in the chest center at the 70th General Hospital, Pistoia, Italy, the following day, there was considerable bile-stained fluid in the right chest. The fluid rapidly became purulent and showed persistently large percentages of bile. Later, roentgenologic examination revealed a right subphrenic abscess (fig. 41A).

In preparation for surgery, the patient was given 1,500 cc. of blood in 48 hours, which restored the hematocrit value to 40. He was also given penicillin systemically. Exploration on 28 April, 2 weeks after injury, revealed a large subphrenic abscess and an extensive bile empyema. The one-stage operation performed consisted of drainage of the subphrenic abscess, decortication of the lung, excision of the fistula, and closure of the diaphragm with interrupted silk sutures. Decortication was accomplished without difficulty, and pulmonary reexpansion was prompt and complete. The fistulous opening in the diaphragm, at the site of the previous repair, was excised. With the diaphragm open, the cluster of rubber tissue drains that had previously been placed were carried down to the wound in the liver. The diaphragm was closed in two layers, with interrupted sutures of fine silk. The chest was closed tightly after irrigation of the pleural cavity with physiologic salt solution and the introduction of anterior and posterior intercostal catheters. Penicillin (25,000 units) was instilled into the pleural cavity and left in situ for 6 hours.

The wound healed promptly (fig. 41B), and recovery was uncomplicated and complete (fig. 41C).

Other complications.—Bronchobiliary fistulas were infrequent. One patient with this complication died of unexplained, massive retroperitoneal hemorrhage while he was being prepared for surgery.

Complications of left-sided thoracoabdominal wounds were sometimes bizarre. In one instance, a soldier with a previously unrecognized congenital diaphragmatic hernia received a chest wound. The colon was perforated, and what amounted to a traumatic colostomy developed; 3 days after wounding,

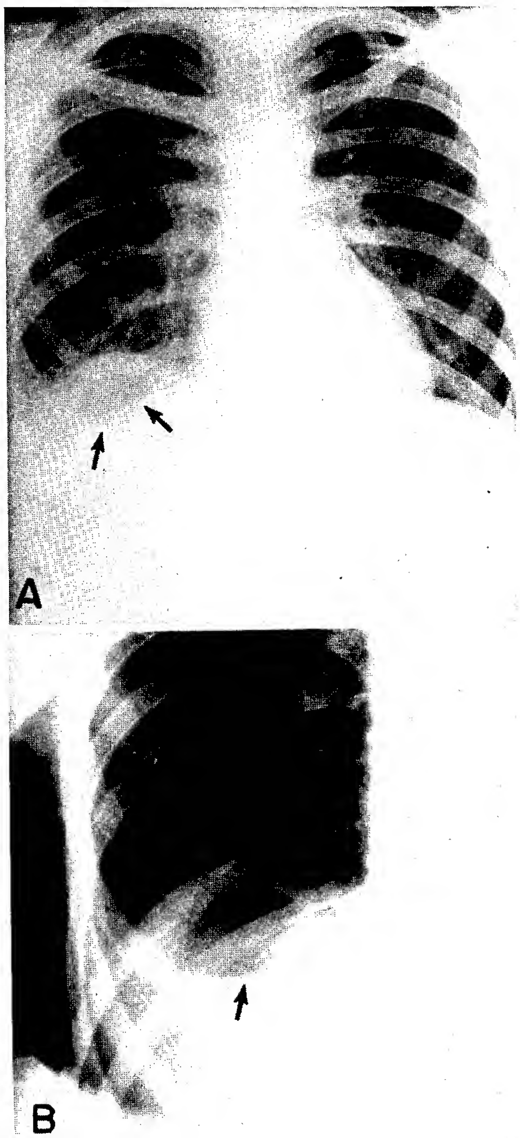

FIGURE 40.—Management of subphrenic abscess secondary to laceration of liver. A. Posteroanterior roentgenogram showing abscess on right. B. Detail posteroanterior roentgenogram showing fluid level, air cap, and elevation of right hemidiaphragm.

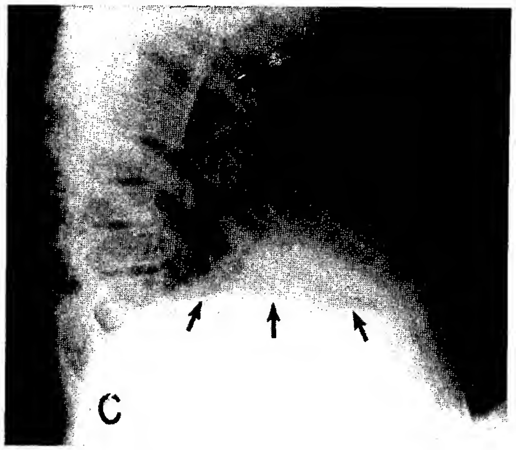

FIGURE 40.—Continued. C. Lateral roentgenogram showing abscess in characteristic anterior position.

feces were found pouring out through the broken-down thoracotomy wound.

Two patients were observed with gastropleural fistulas. In each instance, the gastric repair had broken down and had caused the breakdown of the diaphragmatic repair. Both fistulas were difficult to close because the skin was so badly excoriated from irritating gastric secretions.

An extremely troublesome complication, which fortunately was uncommon, was the so-called plastic type of peritonitis. Presumably, it was caused by the slow leakage of bile into the general peritoneal cavity. The plastic, nonpurulent exudate that resulted matted the loops of intestine together and gave rise to intermittent bouts of partial intestinal obstruction. Prompt decompression by the Wangensteen or Miller-Abbott technique was the usual treatment. Operation was required only in an occasional case.

CASE HISTORIES

The following case histories are illustrative of various aspects of thoracoabdominal wounds:

Case 2.—This soldier was operated on in a field hospital, under endotracheal ether anesthesia, 3 hours after sustaining a severe perforating gunshot wound of the left chest, with abdominal involvement. The chest was entered through a left-sided thoracotomy; an 8-inch segment of the ninth rib was resected.

The chest cavity contained the entire stomach, which was tremendously dilated; a portion of the jejunum; the omentum; the transverse colon with the splenic flexure; and the spleen. The stomach, jejunum, colon, and kidney were found to be intact. The badly lacerated spleen was removed. Insertion of a stomach tube reduced the stomach to 40 percent of its original size. The left gastroepiploic artery, which was torn near its termination, was ligated. A tear in the lesser omentum was repaired. After the herniated

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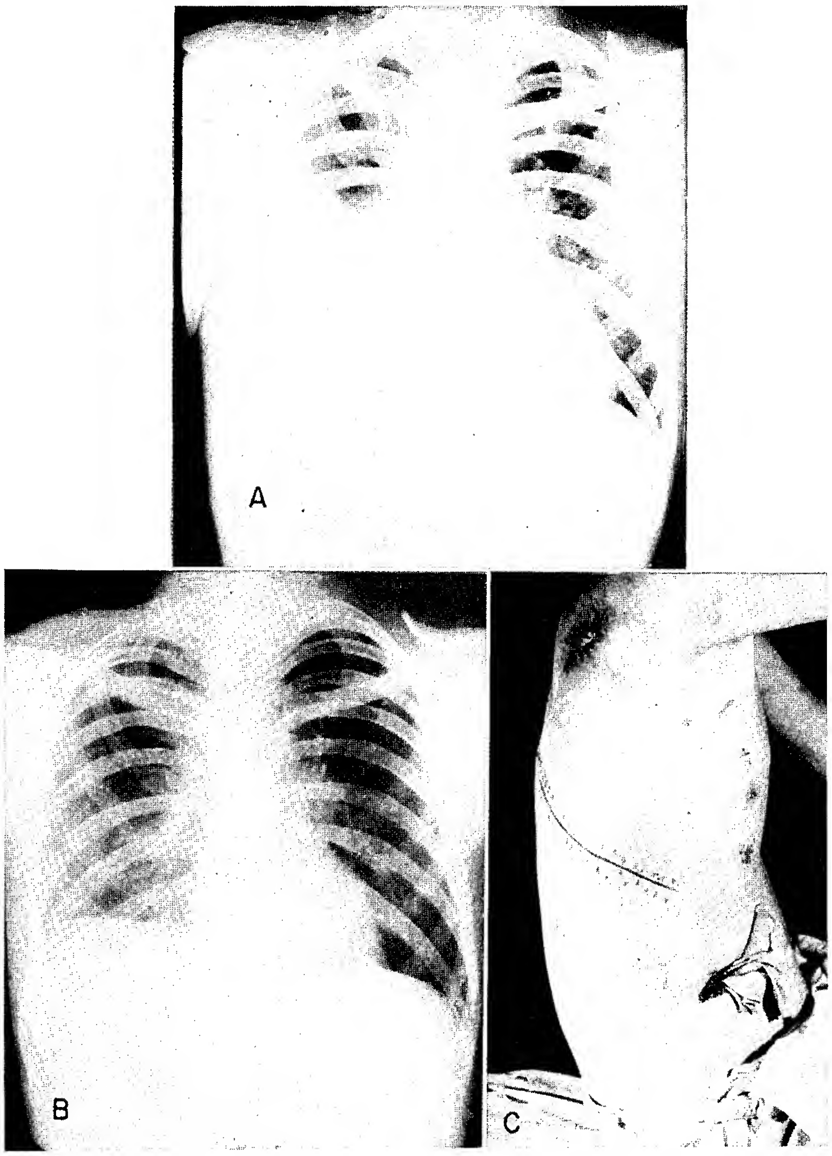

FIGURE 41.—Coexistent bile empyema and subphrenic abscess. A. Posteroanterior roentgenogram showing right-sided subphrenic abscess and bile empyema. B. Same, 10 days after one-stage operation consisting of thoracotomy, drainage of subphrenic abscess, decortication of lung, and closure of biliary fistula in diaphragm. C. Patient 1 week after operation.

organs were replaced in the peritoneal cavity, the diaphragm was closed in two layers with interrupted silk sutures. The tip of the lower lobe of the left lung, which was badly torn and bleeding, was resected, and the wound sutured with fine catgut on a swaged needle. After an intercostal catheter was inserted, closure was effected with pericostal sutures and suture of the muscle layers. The patient was evacuated to a base hospital on the 12th day in excellent condition.

Comment.—This case history typifies the multiple character of left thoracoabdominal injuries because of the close proximity of the organs in the left upper quadrant of the abdomen to each other. The history also demonstrates their ready accessibility through a transthoracic approach. When the diaphragm is opened, they actually rise into the pleural cavity.

Case 3.—This soldier sustained a penetrating shell-fragment wound of the tenth left interspace in the posterior axillary line. The wound was explored at a forward hospital, which came under shellfire during the operation. Closure was therefore hurriedly effected after suture of the diaphragm. When the casualty was received at an evacuation hospital 24 hours later, his record contained a note from the forward surgeon that he "thought a laparotomy should be done." The man was in great pain, and his abdomen was considerably distended.

When the abdomen was opened through a left rectus incision, the peritoneal cavity contained fresh blood, but all viscera appeared intact.

Thirty-six hours after operation, the thoracotomy wound became crepitant and edematous, and a foul odor was noted. When the wound was explored, a typical clostridial myositis of the superficial muscles was found. The muscles were already necrotic. Death occurred 12 hours later. Autopsy confirmed the diagnosis of clostridial myositis of the chest wall and also revealed a perforation of the splenic flexure of the colon.

Comment.—The injury of the retroperitoneal portion of the splenic flexure was not identified at laparotomy in this case. It would probably have been found, and could have easily been handled, had a transthoracic approach been employed.

Case 4.—This soldier was admitted to a field hospital with a rigid abdomen shortly after sustaining a penetrating wound of the right lower chest. Thoracotomy was performed, with resection of the tenth rib, and a laceration of the lower lobe of the right lung was sutured. The diaphragm was perforated and the liver lacerated; the missile lay in the tear. Inspection of the duodenum, hepatic flexure, and kidney revealed no further damage. The wound in the liver was drained subdiaphragmatically before the diaphragm was closed with two layers of interrupted silk sutures. The patient was in good condition when he was evacuated on the sixth postoperative day.

Comment.—This case is one of 17 right-sided thoracoabdominal lesions, 12 of which were handled satisfactorily by the transthoracic approach.

Case 5.—This soldier was received in a field hospital with a blood pressure of 90/50 mm. Hg and a pulse of 140, after having sustained a gunshot wound of the left chest and abdomen. He had received 500 cc. of plasma before admission. No respiratory difficulty was apparent, and breath sounds were present, though somewhat diminished on the left. The abdomen was spastic and moderately tender. He complained of suprapubic pain.

The wound of entrance, which was 1.5 cm. in diameter, was in the seventh interspace anteriorly, 2 inches from the midline. The ragged wound of exit, 7.5 cm. in diameter, was in the ninth interspace, just medial to the posterior axillary line. Aspiration of the left chest produced about 30 cc. of blood and a small amount of air.

After a plasma transfusion of 500 cc. had been given, a blood transfusion was started and ether-oxygen anesthesia induced. A subcostal laparotomy incision was made. Exploration revealed approximately 800 cc. of blood, mixed with gastric contents, in the peritoneal cavity. The stomach was greatly distended. The lesser peritoneal cavity was not involved. The spleen was lacerated, and a perforating wound was found in the cardia.

The wounds of entrance and exit in the cardia were closed in two layers with chromic catgut by the inverting technique. When the spleen was delivered, a 6-cm. sucking laceration of the posterior portion of the diaphragm became evident. It was closed with difficulty after the spleen had been removed. Another nonsucking laceration of the diaphragm was easily repaired. The abdomen was closed in layers.

The patient's condition was not satisfactory at any time during the 90-minute procedure, and he died while the skin sutures were being inserted. At no time did the blood pressure rise above 90/60 mm. Hg, in spite of the continuous administration of blood, and there was a gradual decrease in pressure during the last 30 minutes of the operation.

Comment.—The first error made in this case was failure to have an endotracheal tube in place before the abdomen was opened. The large sucking perforation of the diaphragm was not apparent until the lacerated spleen was delivered and its tamponade effect on the diaphragm was lost. Except for the application of an ineffective gauze pack, the diaphragmatic laceration had to be ignored until splenectomy was completed. Most of the operating time was spent in accomplishing a difficult diaphragmatic closure. The sudden collapse of the left lung was more than an already shocked patient could tolerate. Had endotracheal anesthesia been used, with facilities for maintaining positive intrapulmonic pressure during operation, pulmonary collapse would not have occurred. The major error of management was not to employ the transthoracic approach, through which the entire procedure could have been carried out with a great reduction in risk.

EXPERIENCE OF THE 2D AUXILIARY SURGICAL GROUP

The World War II experience of the 2d Auxiliary Surgical Group in the Mediterranean theater included 903 thoracoabdominal wounds, 247 of which were fatal. These wounds were encountered chiefly during 1944 and 1945, but 68 wounds, 25 of which were fatal, were observed in 1943. During the same 1943–45 period, the teams of this group encountered 1,364 thoracic wounds. Thoracoabdominal wounds thus accounted for almost 40 percent of all wounds of the chest.

Certain data concerning these 903 thoracoabdominal wounds have been cited in the preceding pages. Additional data, and certain conclusions which can be drawn from them, follow.

General Data

The great majority of these casualties were U.S. Army infantrymen, with Wehrmacht prisoners of war accounting for the next largest group. The figures also cover some British and French soldiers and a few civilian casualties.

The age factor was of little significance, as the great majority of the patients were young, healthy males. In the 762 cases in which the age was recorded, there were only 4 patients over 40 years of age. There were 190 casualties 20 years of age and under; 297 in the 21- to 25-year group; 176 in the 26- to 30-year group; and 95 in the 31- to 40-year group.

Artillery and mortar fire was responsible for 590 of the 903 wounds, and rifle, machinegun, and pistol fire for 245. The remaining wounds were caused by bombs, mines, and grenade fragments.

In 837 cases, the missiles entered the abdomen through the thorax. In the other 66 cases, they entered the abdomen and then penetrated the diaphragm. In 418 cases, the wounds were on the right side and in 419 on the left side. In 20 cases in which both diaphragms were perforated, the wound of entry was on the right in 7 and on the left in 13. No information is available on this point in the remaining 46 cases.

Timelag

There was no record of the timelag in 49 cases, 11 of which were fatal. In the 854 cases in which information on this point is available, it varied from less than an hour to more than 30 hours (table 8).

At first glance, the high mortality rate in the group in which the timelag was shortest might seem to invalidate the concept that the earlier a casualty with a thoracoabdominal wound could be operated on, the better were his chances. It does not. The high rate reflects the fact that the nearer the frontline a field hospital is set up, the more casualties will be brought to it who will die there rather than on the battlefield. This was particularly true on the Anzio beachhead, when both field and evacuation hospitals were very far forward because the sector occupied was too small for them to be placed farther back. On the beachhead, one patient died of an injury of the portal vein, and five died of injuries of the vena cava, in hospitals. If the evacuation distance had been longer, they would not have reached them alive.

There were 8 deaths in the 34 casualties who came to operation 30 hours or more after wounding. Two had wounds of the liver, three wounds of the spleen, and one a wound of the kidney. In the two remaining cases, the missile penetrated the peritoneal cavity without damage to any viscera.

Surgical Approach

The transthoracic approach was used in 448 of these 903 thoracoabdominal injuries (table 9). In 86 patients in this group, surgery was limited to thoracotomy, exploration, removal of foreign bodies, or simple retroperitoneal

TABLE 8.—*Case fatality rate according to timelag in 854 thoracoabdominal injuries* [1]

Timelag	Cases	Deaths	Percent
To 6 hours	221	64	28. 9
To 12 hours	400	96	24. 0
To 18 hours	122	39	31. 9
To 24 hours	54	20	37. 0
To 30 hours	23	9	39. 1
Over 30 hours	34	8	23. 5
Total	854	236	27. 6

[1] In 49 of the 903 cases in this series, there was no record of the timelag. There were 11 fatalities in this group.

TABLE 9.—*Case fatality rate according to surgical procedure in 903 thoracoabdominal wounds*

Procedure	Cases	Deaths	Percent
Transdiaphragmatic laparotomy	448	91	20.3
Laparotomy	202	77	38.1
Thoracotomy and laparotomy	144	36	25.0
Laparotomy and thoracotomy	74	26	35.1
Transdiaphragmatic laparotomy and laparotomy	20	7	35.0
Thoracolaparotomy [1]	6	3	50.0
No surgery	3	1	33.3
Death during surgery	6	6	100.0
Total	903	247	27.4

[1] In this technique, the thoracic incision was extended onto the abdomen over the chondral arch.

drainage. In the remaining 362 cases, the entire abdominal procedure, which involved surgery on 31 different combinations of organs, was performed through the chest incision.

In 202 other cases, the entire procedure was abdominal.

A comparison of the case fatality rates in the injuries handled by the transthoracic approach and those handled by the abdominal approach, 20.3 percent versus 38.1 percent, might suggest the far greater superiority of the transthoracic approach. These data should not be so construed. The results in the individual case depended upon the magnitude of the abdominal and thoracic problems (table 7). Generally speaking, however, the results were better if the thoracotomy approach was used for perforating wounds in the upper zone of the left diaphragm or penetrating wounds in which roentgenograms showed that the missile lay within the area of the dome of the diaphragm.

Factors of Mortality

General considerations.—The gross case fatality rate for the 903 thoracoabdominal injuries cared for by surgeons of the 2d Auxiliary Surgical Group was 27.4 percent (247 deaths). These figures are for first priority hospitals, in which the postoperative stay, though it varied from a few days to as long as 18 days, was usually from 7 to 10 days.

Conditions in theaters of operations made it extremely difficult to determine the end results of forward surgery. Reports from evacuation and base hospitals were all to the effect that patients operated on in field hospitals did well after they reached hospitals farther to the rear. It is probable, therefore, that a more complete followup would not have materially altered the case fatality rates in forward hospitals.

There was an interesting and probably significant decrease in the case fatality rates of thoracoabdominal injuries as time passed:

In 1943, there were 25 deaths in 68 cases, 36.8 percent.

Between January and June 1944, there were 84 deaths in 243 cases, 34.6 percent.

Between July and December 1944, there were 98 deaths in 392 cases, 25.0 percent.

Between January and the first week in May 1945, when the war ended, there were 40 deaths in 200 cases, 20.0 percent.

The decreasing case fatality rate in the latter half of 1944 and 1945 coincided with the introduction of penicillin. Antibiotic therapy undoubtedly played a part in the improvement. Another explanation of the improvement is applicable to the first half of 1944, the establishment of a theater blood bank and the increasingly liberal use of whole blood.

Surgeons in the theater, however, believed that the improvement in the case fatality rate could reasonably be assumed to be a reflection of their greater knowledge and experience in dealing with these wounds; a greater appreciation of the implications of the thoracic component and the complications which could arise from it; a greater facility on the part of individual surgeons and anesthesiologists (the so-called learning curve); and a keener appreciation of, and greater attention to, details of resuscitation and of preoperative and postoperative care.

Effect of thoracic and abdominal components of wound.—When the mediastinum was injured, the case fatality rate was 54 percent. Otherwise, it was impossible to discover, from a study of these cases, exactly what effect the chest component of the wound had, beyond the far-reaching influence of cardiorespiratory disturbances that were not promptly corrected.

With these exceptions, there was no doubt that the most lethal part of the wound was the abdominal component. The precise organs injured and the number of injuries below the diaphragm were reflected in the mortality rates (table 7). Wounds of hollow viscera carried a much higher rate than wounds of solid viscera, though an occasional fatality was caused by an overlooked wound of a solid viscus.

The number of organs injured also played an important role. Wounds of five or more viscera were universally fatal. These subjects are discussed in more detail in the volume in this series devoted to abdominal injuries (*1*).

Anatomic considerations.—The side on which the injury was located played a part in the mortality rate, for anatomic reasons. The figures are as follows:

Perforations of the right diaphragm, 435, with 103 deaths (23.6 percent).
Perforations of the left diaphragm, 448, with 136 deaths (30.8 percent).
Bilateral perforations, 20, with 8 deaths (40 percent).

Anatomic reasons are also connected with the case fatality rates for herniation of the abdominal viscera into the chest cavity. In the 5 instances of evisceration into the right pleural cavity there were 2 deaths, against 13 deaths in 35 herniations through the left diaphragm.

Time of death.—The day of death was recorded in 234 of the 247 fatalities:

1. There were 154 fatalities in the first 48 hours, including 49 deaths on the operating table (40 from shock, 4 from hemorrhage, 3 from atelectasis, and 1 each from cardiac tamponade and vagovagal reflex during bronchoscopy). All but 13 of the 130 deaths from shock occurred within this period. The case fatality rate could be directly related to the degree of shock in which the casualties were received:

No signs of shock, 145 patients, 8 deaths (5.5 percent).

Mild shock, 75 patients, 10 deaths (13.0 percent).

Moderate shock, 174 patients, 31 deaths (17.5 percent).

Severe shock, 275 patients, 164 deaths (59.6 percent).

There is no record of the degree of shock in the remaining 234 cases, in which there were 34 deaths (14.5 percent).

In addition to shock, chiefly due to blood loss, deaths early in the postoperative period were caused by uncorrected (occasionally irreversible) disturbances of cardiorespiratory physiology, overwhelming contamination and infection of the peritoneal and pleural cavities and retroperitoneal space, and massive tissue destruction.

2. There were 28 deaths between the third and fifth days. Of these, 13 were due to renal failure, as evidenced by oliguria and anuria (vol. I); peritonitis and pneumonia were the next most frequent causes.

The 22 deaths from peritonitis occurred between the day of operation and the 10th postoperative day. The fact that 17 had occurred by the end of the third day is evidence of the catastrophic effect of the so-called contamination type of peritoneal infection, with sudden, massive soiling of the cavity.

3. There were 10 deaths from pulmonary embolism, all between the day of operation and the 11th postoperative day; 6 occurred within the first 72 hours.

Other occasional causes of death included missed perforations of hollow viscera, mismatched blood, blast injury, mediastinitis, empyema, fat embolism, pressure pneumothorax with bronchopleural fistula, liver death, clostridial myositis, disruption of the diaphragm, morphinism, and meningitis.

Associated wounds.—Wounds in other parts of the body accounted for some of the 247 deaths in this series or played an important part in the fatality. Of the 385 associated wounds, 161 were classified as mild, and the 34 deaths in this group (21.1 percent) can probably be attributed entirely to the thoracoabdominal wounds. The same reasoning perhaps holds for the majority of the 129 associated injuries of moderate severity, in which there were 33 deaths (25.6 percent). In the 95 associated injuries classified as severe, there were 36 deaths (37.9 percent). There can be no doubt that in many instances in this group the associated injuries played an important role, if not the major role, in the fatality. Among these 95 severe associated wounds there were:

26 cord injuries, with 16 deaths.

7 brain injuries, with 1 death.

15 fractures of the femur, with 4 deaths.
9 traumatic amputations, with 3 deaths.
8 other abdominal (not thoracoabdominal) wounds, with 4 deaths.

The influence of severe associated wounds is evident in a casualty cared for by Maj. (later Lt. Col.) Reeve H. Betts, MC. This was the only casualty with a thoracoabdominal wound to die before operation in the 29 such injuries handled by his team. This soldier had a right traumatic thoracotomy, a left thoracoabdominal wound, a traumatic amputation of the right arm, and a severe wound of the right thigh. In spite of vigorous attempts at resuscitation, including the administration of 500 cc. of plasma and 3,500 cc. of blood, his blood pressure was never obtainable, and he died 5 hours after wounding.

It might be added that associated wounds, in addition to the part they played in the case fatality rate of thoracoabdominal wounds, also played a major role in their morbidity.[4]

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1. Medical Department, United States Army. Surgery in World War II. General Surgery. Volume II. Washington: U.S. Government Printing Office, 1955.
2. Snyder, Howard E.: The Consultant in Surgery, Fifth U.S. Army. *In* Medical Department, United States Army. Surgery in World War II. Activities of Surgical Consultants. Volume I. Washington: U.S. Government Printing Office, 1962, pp. 333–464.

[4] The reader is referred to chapter XI (p. 441) for long-term followup studies on casualties with thoracoabdominal wounds.

746-941v—65——12

Part II

COMPLICATIONS OF WOUNDS OF THE CHEST

CHAPTER IV

Complications and Sequelae

Thomas H. Burford, M.D.

Except for two or three immediate complications, such as tension pneumothorax, hemorrhage, and acute gastric dilatation, almost any of the complications of wounds of the chest might occur at any time after wounding. It was therefore necessary to be on the watch for them, and to try to forestall their occurrence, at all times.

While the attempt to separate them chronologically is somewhat academic, the complications of chest wounds may be divided, generally speaking, into (1) early and (2) late or delayed complications as follows:

Early complications included tension pneumothorax, hemorrhage, acute gastric dilatation, emphysema, pulmonary edema, atelectasis, hematoma of the lung, bronchopleural fistula (which sometimes was persistent), wound disruption, clostridial myositis, and chylothorax.

Delayed complications included abscess of the lung, pneumonitis and pneumonia, chronic parietal sinuses, defects of the chest wall, adhesive pleuritis (infolded lung), traumatic osteomyelitis, and abscess of the mediastinum.

The important sequelae of chest injuries in World War II were diaphragmatic hernia, hernia of the lung, and a group of residual symptoms, of which pain and dyspnea were the most prominent.

TENSION PNEUMOTHORAX

General Considerations

Pathogenesis.—Tension or pressure pneumothorax might be of four origins (figs. 42 and 43):

1. It might result from a pulmonary laceration in which a tangential opening in the lung acted as a check valve, so that, during inspirations, gradually increasing amounts of air were trapped in the pleural cavity. The flap of lung prevented the escape of air into the bronchial tree on expiration. Most tension pneumothoraces were of this origin.

2. It might result from small perforating associated wounds of the subglottic larynx or the cervical trachea. In the latter type of wound, air dissected along the fascial planes to the mediastinum and might break into one or both subcavities. Tension pneumothorax of this origin was infrequent.

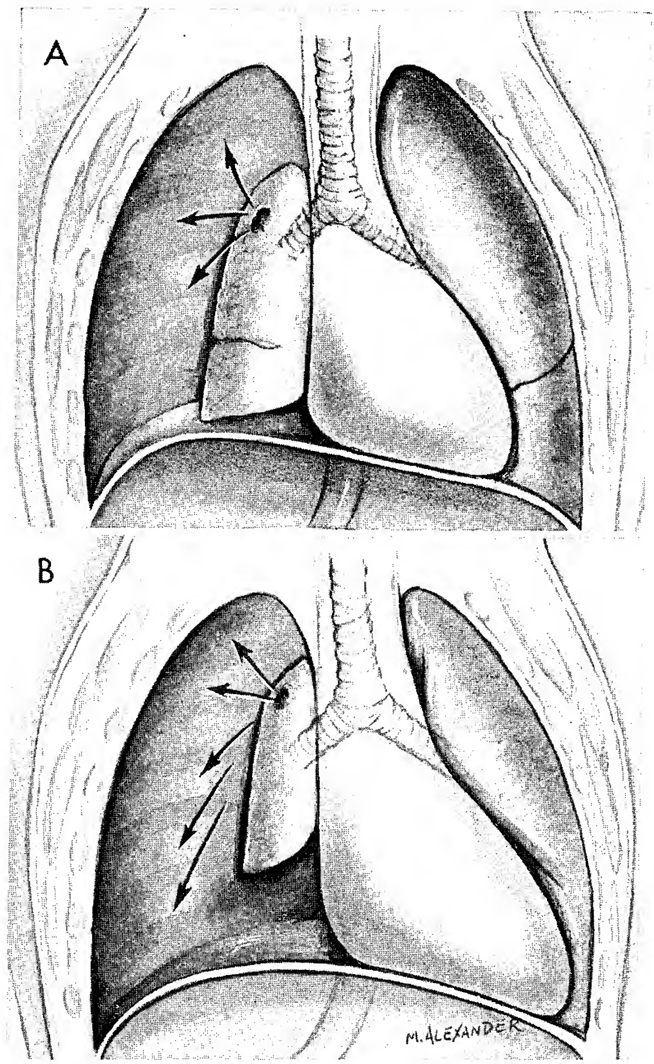

FIGURE 42.—Pathologic physiology of tension pneumothorax. A. Pneumothorax of moderate extent. As air escapes into the pleural cavity, the affected lung collapses, and there is moderate mediastinal shift to the unaffected side. B. Tension pneumothorax. The uninvolved lung, as well as the involved lung, is now collapsed, as the result of mediastinal shift to the uninvolved side. Shock increases as the result of collapse of the superior and inferior venae cavae, and because of the decreased venous return to the heart associated with the marked mediastinal shift.

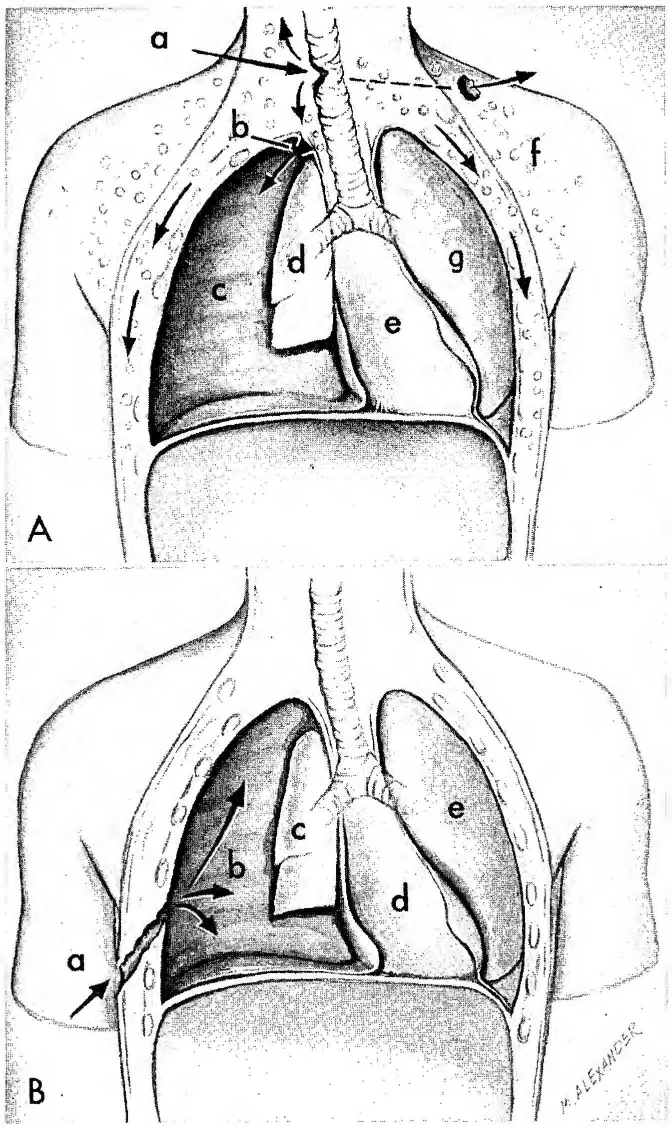

FIGURE 43.—Tension pneumothorax of various origins. A. Tension pneumothorax resulting from laceration of cervical trachea and mediastinal pleura, showing: Laceration of cervical trachea (a), laceration of mediastinal pleura (b), tension pneumothorax (c), collapsed lung (d), shift of heart (e), subcutaneous emphysema (f), and partial collapse of contralateral lung (g). B. Tension pneumothorax resulting from sucking wound of valvular type, showing: Valvular sucking wound of chest wall (a), tension pneumothorax (b), collapsed lung (c), cardiac shift to intact side (d), and partial collapse of contralateral lung (e).

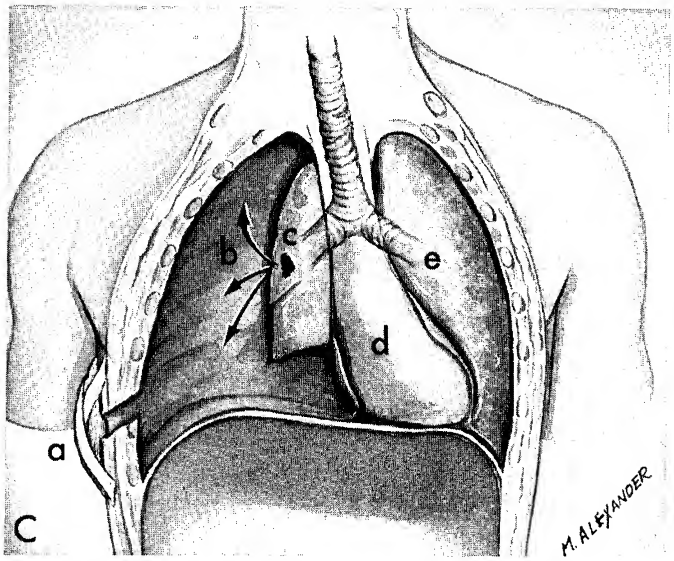

FIGURE 43.—Continued. C. Tension pneumothorax resulting from pulmonary laceration following packing of sucking wound, showing: Sucking wound with airtight packing (a), laceration of lung, permitting egress of air into pleural cavity (b), collapse of the lung (c), cardiac shift to intact side (d), and partial collapse of contralateral lung (e).

3. It might result from the ingress of air through the thoracic wall in a sucking wound.

4. It might follow the emergency closure of a sucking wound in forward areas, without provision for release of trapped air or the continued escape of air into the pleural cavity.

An occasional tension pneumothorax occurred during operation for thoracoabdominal wounds (p. 103).

Incidence.—Tension pneumothorax as the result of trauma was encountered only infrequently in forward hospitals, though it was somewhat more common as a postoperative or posttherapeutic complication. Its infrequency is evident in the statistics of the 2d Auxiliary Surgical Group. It was encountered by this Group only 11 times in its 2,267 thoracic and thoracoabdominal injuries. It is doubtful, furthermore, that all of these 11 cases were examples of true tension pneumothoraces, since the valvelike mechanism that produces it and that permits easy ingress, but difficult egress, of air was not always found. In occasional cases in which air was found under more than normal pressure, or even above atmospheric pressure, the explanation was usually either compression of air by intrapleural bleeding or, most often, the irregular, splinting type of respiration that was the result of pain in the chest wall.

The infrequency of pressure pneumothorax probably has several explanations:

1. The preponderance of shell-fragment wounds, which resulted in a preponderance of large defects of the chest wall. For physical reasons, air could not be entrapped in the chest in such wounds.
2. The routine application of occlusive dressings tightly enough to end the sucking or blowing effect of the open chest wound but not so tightly that a tension pneumothorax was built up.
3. The almost routine use of a flapper-valve decompressive catheter in collecting stations or battalion aid stations.
4. The excellent screening of inductees in World War II, as a result of which preexistent restricting pleural adhesions, which were rather frequent in World War I soldiers, were extremely uncommon.

The majority of tension pneumothoraces observed in World War II resulted from continued leakage of air from the lacerated pulmonary parenchyma. If such a laceration existed and was leaking air, closure of the external chest wound converted the open pneumothorax into a progressive tension pneumothorax. This type of tension pneumothorax was also uncommon, possibly because bleeding from the pulmonary laceration usually stopped promptly and the hematoma that surrounded the torn parenchyma produced a sufficient area of nonaeration to limit the amount of air that reached the pleural cavity until the laceration was sealed over by natural processes.

Continued leakage of air occasionally had unusual explanations. A retained missile might offer a physical obstacle to natural closure of the air leak in the lung (fig. 44), or there might be a leak through a laceration in one of the larger bronchi. Two unusual cases of tension pneumothorax were observed by surgeons of the 2d Auxiliary Surgical Group:

In one case, the tension pneumothorax developed from a perforating wound of the subglottic larynx: the air dissected the fascial planes of the mediastinum and perforated into the pleura. Tracheotomy was necessary to short circuit the column of air.

In the other case, an instance of crushing injury, the patient sustained wounds of the lower esophagus, mediastinum, diaphragm, and stomach, and the air in the pleural cavity was swallowed air.

An occasional tension pneumothorax was of extreme degree (fig. 45). That it could be survived was striking proof of the tremendous respiratory reserve of the young, well-conditioned fighting men who made up the battle casualties.

Clinical picture.—Extreme dyspnea was the most prominent symptom of tension pneumothorax. The patient preferred to sit upright or semierect. His worried, anxious expression indicated that he was fighting for breath.

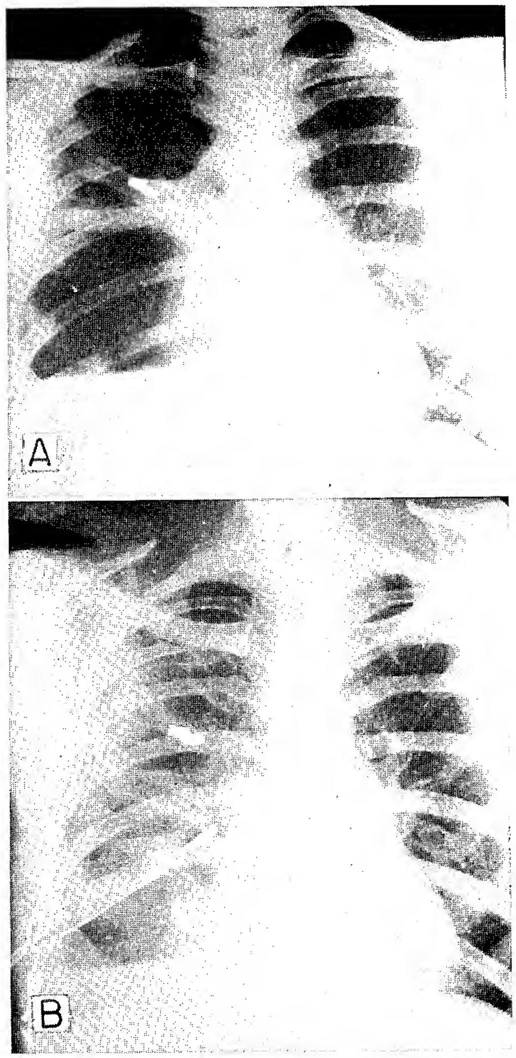

FIGURE 44.—Pressure (tension) pneumothorax. A. Posteroanterior roentgenogram showing pressure pneumothorax of moderate degree with retained foreign body. B. Same 24 hours later, showing prompt reexpansion of injured lung. Leakage of air continued, however, and thoracotomy 5 days after wounding showed that the presence of the missile offered a physical obstacle to natural closure. It was lying in the periphery, only partly embedded in the pulmonary parenchyma. The catheter functioned well, though it had been introduced farther than was necessary. Operation was performed without difficulty on the totally equilibrated patient, and recovery was prompt.

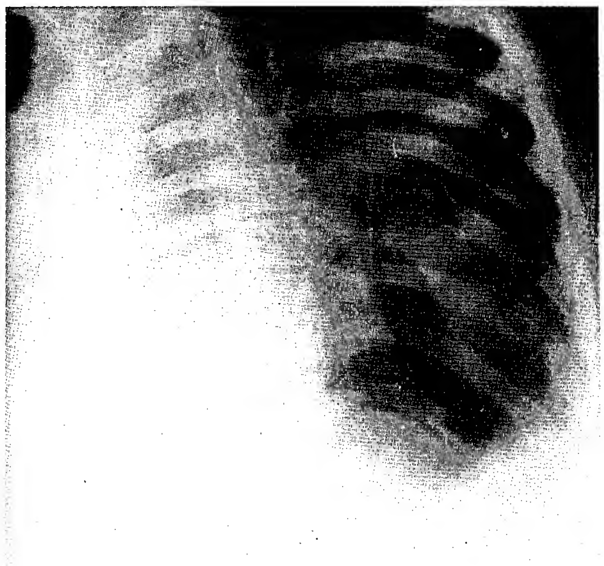

FIGURE 45.—Lateral roentgenogram showing extreme degree of pressure pneumothorax with mediastinal shift. This patient recovered without complications after reduction of the tension pneumothorax.

Cyanosis, which might not be present originally, became increasingly prominent as mediastinal shift caused interference with cardiac action. The veins of the neck also became prominent. Physical examination revealed hyperresonance of the involved hemithorax, with absence of breath sounds (the so-called silent resonant chest) and a shift of the heart and mediastinum to the opposite side.

Management

The emergency management of tension pneumothorax has been discussed under resuscitation (vol. I).

If emergency measures were not required (that is, if the compression of the lung did not exceed 25 or 30 percent and if dyspnea were not a feature), the practice was merely to observe the patient carefully for 10 to 14 days. In most instances, pulmonary reexpansion had occurred by this time, and no treatment was necessary.

In cases of any consequence, pneumothorax was best handled by the prompt insertion of a water-seal intercostal catheter of sufficient size (30–36 F.) to produce immediate decompression of the chest. As a rule, this procedure was followed by prompt reexpansion of the lung (fig. 46), without which neither resuscitation nor recovery could insure.

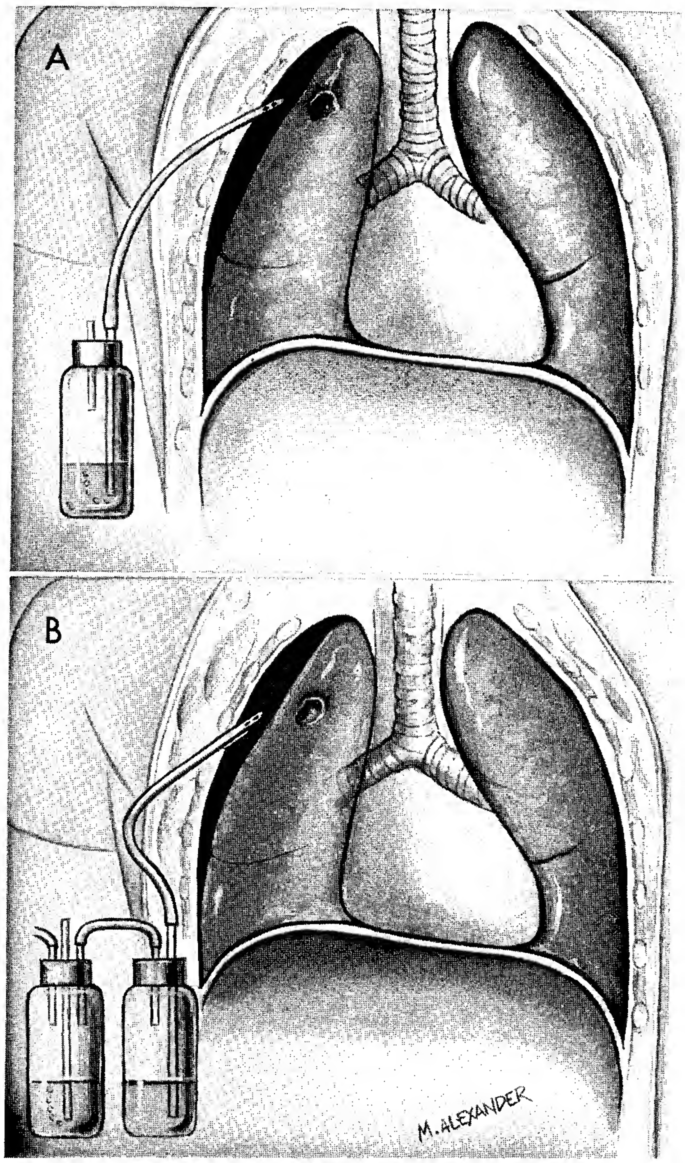

FIGURE 46.—Management of tension pneumothorax. A. Closed catheter drainage, with catheter high in pleural cavity. This is the decompression procedure of choice. B. Constant decompression of chest with negative suction, which is required when leakage of air is persistent. The addition of a second bottle is important in this technique: A glass tube, open to the air, passes through the third opening in the cork, and the amount of suction varies with the distance this tube is under water.

HEMORRHAGE

Incidence

There is surprisingly little discussion in the military literature of hemorrhage caused by wounds of the chest. The explanation is probably threefold:

1. Casualties with bleeding from one of the vessels in the pulmonary hilus or from the other great vessels of the thorax or from the heart usually died on the battlefield or in the battalion aid station. They seldom survived to reach a field hospital.
2. Bleeding from other vessels of the chest was not usually a problem.
3. Another explanation of the infrequency of severe bleeding in chest wounds was that the first effect of parenchymal bleeding into the pleural cavity was compression of the lung. In many instances, hemothorax had the mechanical effect of ending the hemorrhage by compressing the blood vessels.

There were, of course, exceptions to the generalization that all casualties with bleeding from the major thoracic vessels died promptly. In the Mediterranean theater, survivals were recorded after lacerations of the azygos and hemiazygos, and even after a laceration of the superior vena cava, but they were most unusual.

Two casualties with vascular injuries of magnitude were observed by Maj. (later Lt. Col.) Paul C. Samson, MC, in a field hospital. In the first case, a laceration of the right innominate vein was controlled by packing, but death followed a massive recurrence of the hemorrhage 24 hours later. The second patient presented massive bleeding at the left apex, presumably from the subclavian vein. His condition was critical, but rapid reflection of the clavicle permitted the blind placement of mass ligatures and control of the hemorrhage before he became exsanguinated. Recovery ensued but was complicated by a serious pleural infection.

Severe bleeding in chest wounds observed at field hospitals most often arose from one of the systemic vessels, such as the intercostal, the pericardiophrenic, or the internal mammary vessels. The most serious hemorrhages occurred from the internal mammary and the intercostal vessels, from both of which it was likely to be brisk. On the other hand, while complete division of these or any other thoracic vessels might cause severe intrapleural hemorrhage, it was unusual to find active bleeding at operation, even if from 1,000 to 2,000 cc. of blood had previously been aspirated from the chest. The explanation was physiologic: The reduction in blood pressure caused by the blood loss and the subsequent reduction in blood volume had allowed the vessels to retract and become sealed off. The most frequent source of bleeding at operation was an intercostal artery that had been incompletely divided and therefore was unable to retract.

The actual infrequency of serious bleeding in thoracic wounds is evident in the analysis of 200 penetrating and perforating wounds of the chest, including

55 thoracoabdominal wounds, observed in forward hospitals by Maj. (later Lt. Col.) Lawrence M. Shefts, MC, and Capt. (later Maj.) Ernest A. Doud, MC. Active bleeding from the intercostal arteries was found at operation 10 times and from the internal mammary arteries, from the mediastinal vessels, and from the heart in 2 cases each. This is a combined frequency of 8 percent.

It had previously been the practice of these observers to expose the intercostal vessels routinely at operation, for fear of hemorrhage. They abandoned the practice after finding in these 200 cases, 33 lacerations or transections of these arteries in all of which bleeding had ceased by the time operation was done. In this series, all of the bleeding vessels were found in one of two areas, (1) the area extending from the origin of the vessel to the angle of the ribs or (2) the area extending approximately 6 cm. from the lateral border of the sternum.

In 4 of the 200 cases observed by Major Shefts and Captain Doud, bleeding of considerable magnitude occurred from lacerations in the upper half of the upper pulmonary lobes. It was readily controlled by suture. Hemorrhage of similar degree was not observed from lacerations of the same extent in other pulmonary lobes, probably because the injuries in the other lobes involved vessels of smaller size than the comparable lacerations in the upper lobes.

Diagnosis and Indications for Thoracotomy

Continued hemorrhage into the tracheobranchial tree was readily recognized by the reappearance of fresh blood after repeated attempts to clear the airway. Otherwise, external evidences of bleeding were few; in chest wounds, the most serious bleeding was usually internal.

It was not safe to make the diagnosis of intrathoracic bleeding solely on the basis of the pulse rate, blood pressure, respiration, and general status. Some patients with actively bleeding intercostal vessels remained in surprisingly good condition.

The most reliable guides to the existence of continued serious hemorrhage were:

1. Failure of the blood pressure to rise after apparently adequate transfusion.
2. A fall in a blood pressure that had risen to relatively normal levels.
3. Reaccumulation of 1,200 to 2,000 cc. of blood in the pleural cavity within 24 hours after the initial aspiration of similarly large amounts.
4. Persisting severe anemia, in spite of blood replacement, as determined by serial hematocrit determinations.
5. Plotting of the probable course of the missile with reference to the vascular supply.

It proved difficult to generalize on how much bleeding constituted life-endangering thoracic hemorrhage. The fact that from 1,000 to 1,500 cc. of blood could be aspirated from the pleural cavity within 12 to 18 hours after

injury was not, in itself, an absolute index of lethal bleeding. Nearly all the patients who had lost blood in these and even larger amounts responded promptly to massive blood replacement, and subsequent aspirations produced progressively smaller amounts of bloody fluid.

Decision for or against exploratory thoracotomy on the basis of the criteria just listed proved entirely satisfactory during periods of relative quiet, when casualties were admitted in small numbers and surgeons had time for deliberate consideration and watchful delay. During rush periods, when they were confronted with large numbers of casualties, their judgment was often sorely tried. Their decisions became more accurate in proportion to the number of casualties they encountered.

The general policy was followed of exploring any injury in which there was a reasonable doubt concerning the possibility of active intrathoracic hemorrhage. In the really urgent cases, in which procrastination would have been disastrous, there was seldom any doubt of the need for surgery.

Management

The techniques employed at operation for intrapleural hemorrhage were those ordinarily employed in vascular surgery. In hemorrhage from the internal mammary artery, it was imperative that both ends of the damaged vessel be ligated, since hemorrhage could occur from either end. If emergency access to the great vessels proved necessary, it could be obtained at once by reflecting the clavicle and cutting through the manubrium sterni obliquely with a Gigli's saw. This technique, devised by Col. Johan Holtz, chief consultant in surgery to the Norwegian Forces in the United Kingdom, was preferable to section of the clavicle or to sternoclavicular disarticulation.

The prewar expectation that lobectomy would frequently be necessary in parenchymal lacerations, especially those extending into the hilus and involving large vessels, was not fulfilled, nor was the expectation that total pneumonectomy might be necessary in some cases (p. 18).

The possibility of the postoperative recurrence of a preoperative intercostal hemorrhage had always to be kept in mind when the intercostal vessels had not been exposed at operation. The experience of Major Shefts and Captain Doud (p. 153) showed that the policy of nonexposure was safe. There were no deaths from any cause in the first 35 patients in whom, on the basis of their previous experience, they did not expose the intercostal vessels at operation.

Case Histories

Case 1.—A casualty wounded by a high explosive shell fragment that perforated the right upper chest had a sudden massive hemorrhage shortly after his admission to a field hospital. Blood filled the entire trachea and the primary branches of the bronchus.

Bronchoscopy cleared the trachea only temporarily. Hemorrhage continued from the orifice of the right upper lobe bronchus. The patient was taken to the operating room

immediately. Hemorrhage could be controlled only by packing this orifice and holding the packing in place by packing the entire right main stem bronchus. It was then possible to perform a thoracotomy and suture the injuries in the bronchus and lung. The patient made a good recovery and had a fully expanded lung 1 month later.

Comment.—As this case illustrates, massive hemorrhage was always a possibility in chest injuries, infrequent though it might be. This patient's life was saved by his immediate transfer to the operating room and the bold and imaginative measures by which bleeding was controlled.

Case 2.—This patient was admitted to a field hospital 5 hours after he had sustained a penetrating wound of the left chest and penetrating wounds of the right upper arm and left neck. The wound of entrance in the chest injury was in the left part of the neck. Several attempts at aspiration of a large hemothorax were unsuccessful, and it was concluded that the blood had clotted. The wound of the neck was debrided, and the track was explored in the area in which it ran superior to the first rib.

Aspiration was not attempted for the first 3 days after operation. On each of the next 5 days, from 400 to 500 cc. of blood was removed. On the 11th day, the yield was 900 cc. of thin, bloody fluid. During this time, the patient received numerous transfusions.

On the 12th day after wounding, the patient suddenly went into severe shock. Neither the blood pressure nor the radial pulse could be obtained. The respiration was slightly labored, and the skin was cold and clammy. Breath sounds on the left side of the chest were distant. The patient rallied after receiving 1,000 cc. of blood. Attempts at aspiration of the left chest were not successful.

The following (13th) day, 400 cc. of blood-tinged fluid was aspirated. The pulse ranged to 148. After the aspiration, under endotracheal anesthesia, a sickle-shaped incision was made, extending from the mid third of the clavicle to the fifth costosternal junction. The first rib was excised at the sternocartilaginous junction. As the pleural cavity was entered, copious amounts of blood poured out. The second, third, and fourth ribs were severed at the sternocartilaginous junction, and through the exposure thus secured, it could be seen that the bleeding was in the region of the subclavian artery and innominate vein. The bleeding point was compressed by the finger until it could be controlled by gross clamping and mass suture of the vessels at the apex of the chest. The chest wall was closed with catgut sutures for the muscle and fascia and silk for the skin. A catheter was inserted into the eighth intercostal space.

Although blood had been started in both ankles and the right arm as the operation was begun, the blood pressure was imperceptible during most of the procedure. During the operation and the immediate preoperative period, a total of 3,750 cc. of blood was given. An hour after operation, the blood pressure was 100/60 mm. Hg, and oxygen was discontinued. Four hours later, the blood pressure was 102/80 mm. Hg.

The postoperative course was without incident for the next 13 days. Then the hospital blew down in a severe snowstorm, and this patient, along with 700 others, was evacuated to another forward hospital, and 4 days later to a general hospital. When he was received in the latter, the intercostal catheter was not draining, and he was dyspneic and distressed. Several days later, a large drainage tube was inserted in the bed of the eighth rib, to drain a well-established empyema. Recovery thereafter was uneventful.

Comment.—In this case, the direction taken by the missile and the early clotting of the hemothorax pointed to the possible laceration of a large blood vessel. In the absence of shock and other evidence of gross bleeding, thoracotomy seemed to be contraindicated. Subsequent events showed that it would have been the better procedure. The subclavian artery and innominate vein had apparently been partially lacerated, and local infection completed the severance 12 days after wounding. This patient's life was unquestionably saved by the introduction of blood into three veins during the operation.

ACUTE GASTRIC DILATATION

Acute gastric dilatation was a frequent occurrence in both thoracic and thoracoabdominal wounds and was often sufficient to cause respiratory embarrassment. Its recognition was important before operation. Unless decompression was carried out, regurgitation would occur, and gastric contents might be aspirated, with the usual serious consequence.

Routine decompression by the Miller-Abbott or Wangensteen techniques was carried out after operation in all thoracoabdominal wounds until all risk of acute dilatation was past. The same method was used if this complication developed, as it sometimes did, after surgery limited to the thorax.

EMPHYSEMA

Surgical emphysema was not frequent in World War II, probably because of the low incidence of preexisting pleuropulmonary disease in U.S. soldiers. It was of two types, superficial (subcutaneous) and mediastinal.

Subcutaneous Emphysema

The superficial variety of surgical emphysema resulted from penetration of the lung by a missile or by indriven fragments of fractured ribs. In either type of wounding, air escaped into the subcutaneous tissue (1) directly from the lung if adhesions were present, or (2) indirectly, through the medium of an interposed pneumothorax. The trapped air then spread upward to involve the tissues of the neck and face or downward to involve the abdominal wall. Occasionally, the extremities were involved.

Diagnosis was readily established by the crackling sensation felt on palpation of the involved area. Roentgenograms confirmed the presence of air in the tissues. Recognition was important because of the possible association of tension pneumothorax. The only condition which required differentiation was clostridial myositis, which is also characterized by crepitation in the tissues.

Superficial emphysema seldom required any special treatment. Once the opening in the pleura became sealed, which usually happened promptly, the air in the tissues was readily absorbed. If the pleural opening did not close and the air in the tissues increased progressively, a needle was introduced into the pleural cavity to permit the air to escape.

Mediastinal Emphysema

Mediastinal emphysema (fig. 47) was a much more serious condition than subcutaneous emphysema. Air escaped into the mediastinum because of dam-

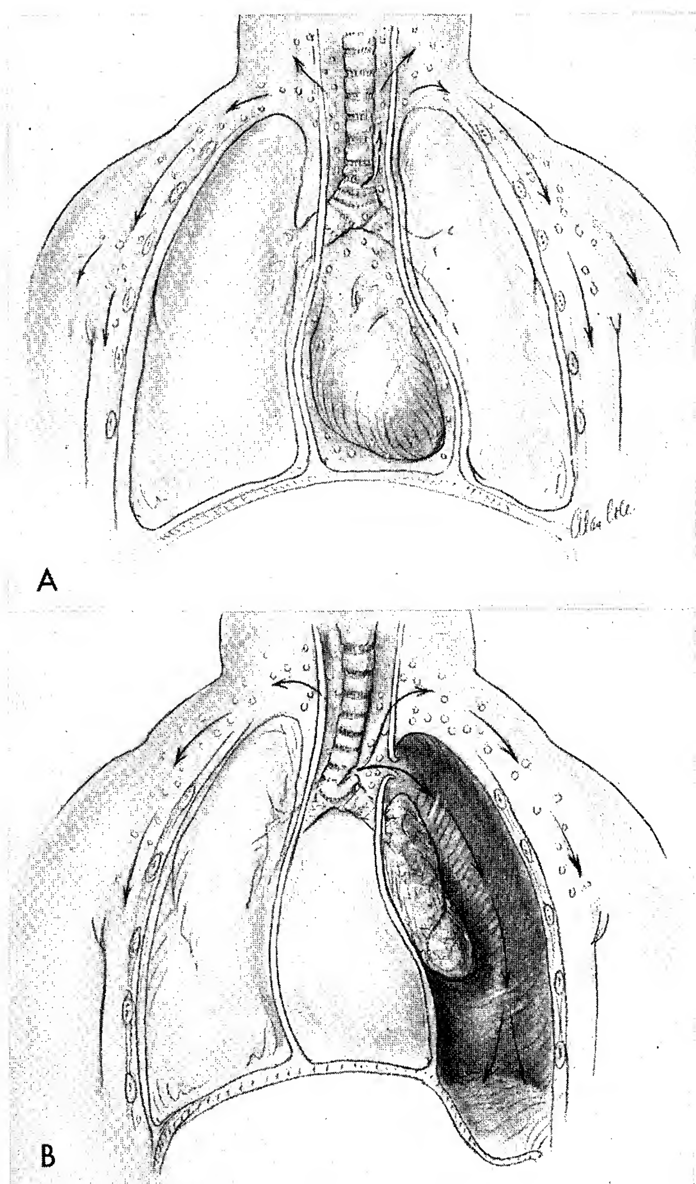

Figure 47.—Schematic showing of pathologic physiology of mediastinal emphysema. A. Leakage of air through penetrating wound of trachea or bronchus, or rupture of these structures, finding its way (as shown by arrows) first into superior thoracic inlet and then upward into neck and head and downward into trunk and upper extremities. B. Tension pneumothorax, which may be rapidly fatal, caused when air in mediastinal emphysema ruptures the mediastinal pleura.

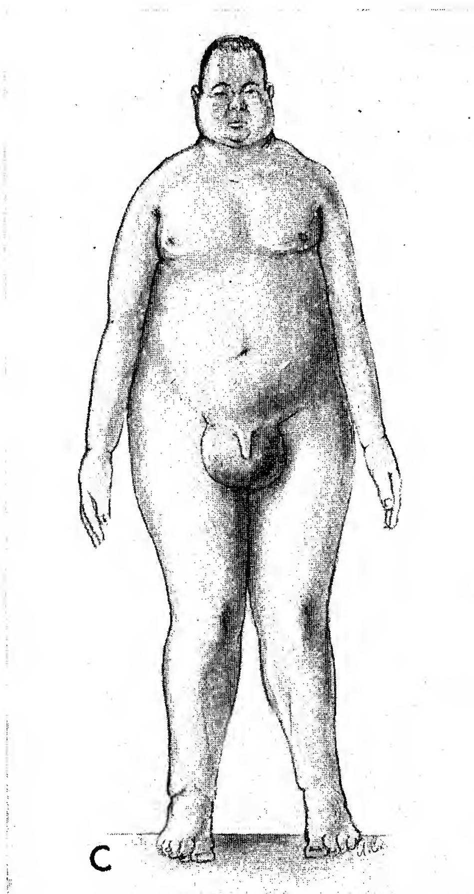

FIGURE 47.—Continued. C. Extensive mediastinal and subcutaneous emphysema. This process, although it presents an alarming picture, is compatible with life if it is not accompanied by tension pneumothorax.

age to the extrapleural, intramediastinal segments of the tracheobronchial tree. If it could escape into the pleural cavity, a tension pneumothorax developed. If it had no route of escape, there was serious danger of compression of the great vessels and even of the esophagus.

Diagnosis was easily made by palpation of the soft swelling in the suprasternal notch. It was confirmed by roentgenograms.

As a rule, decompressive intubation of the pleural cavity was sufficient for relief of the condition (figs. 48 and 49). Tracheotomy was sometimes necessary. Radical treatment was indicated only when the symptoms of compression were severe enough to endanger life. In such cases, the swelling in the neck could be incised, or, if this measure was not effective, cervical mediastinotomy could be employed. So far as is known, this operation was not required in any patient in the Mediterranean theater.

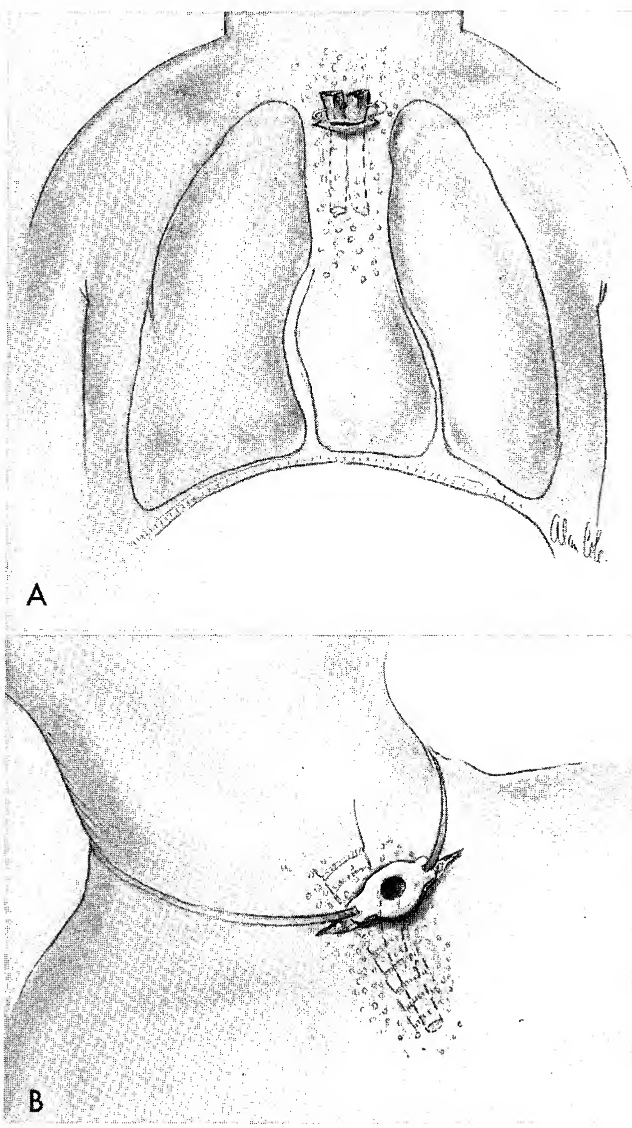

FIGURE 48.—Management of mediastinal emphysema. A. Decompression of air leak of moderate size by insertion of Penrose drains through transverse incision in suprasternal space. B. Tracheotomy in advanced mediastinal emphysema, to permit aspiration of secretions and facilitate administration of oxygen.

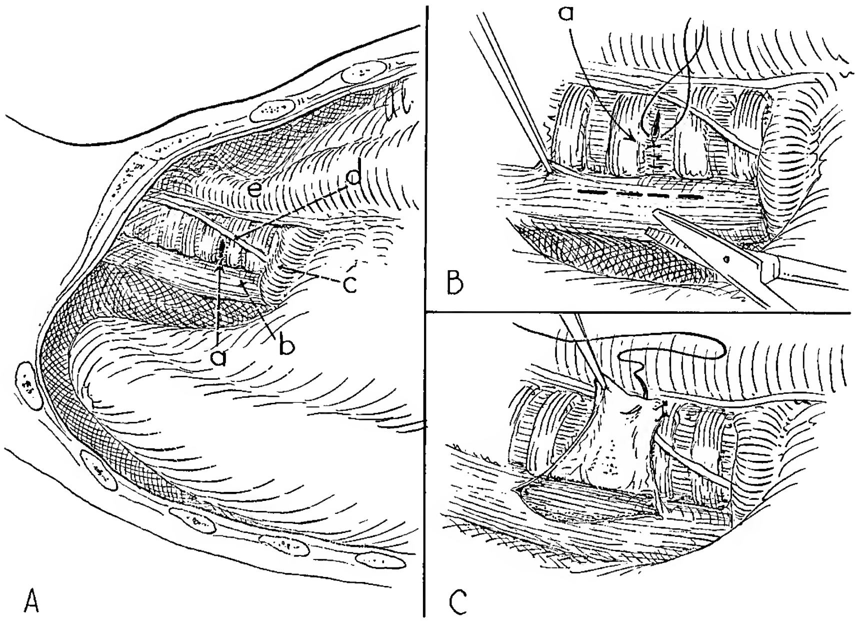

FIGURE 49.—Management of mediastinal emphysema. A. Open repair of laceration of trachea, necessary when air leak is persistent or is associated with pneumothorax not controlled by closed suction drainage: Laceration of trachea (a), esophagus (b), azygos vein (c), vagus nerve (d), and superior vena cava (e). B. Insert showing detail of tracheal repair. Suture of laceration at right angles to long axis of trachea, to prevent obstruction is shown in (a). C. Reinforcement of repair with pedicled muscle or pleural graft.

PULMONARY EDEMA

Pulmonary edema was a possibility in all thoracic wounds and frequently occurred with wounds in other parts of the body. It was most often associated with, or caused by, one of the following conditions:

1. Severe pulmonary contusions, in which it tended to appear early.
2. Dyspnea and anoxia, in both of which, as Drinker and Warren (*1*) showed, pulmonary transudation is frequent.
3. Too rapid administration of intravenous fluids, or the administration of fluids in too large quantities.
4. Fat embolism, which most often was a complication of an associated fracture.
5. Lower nephron nephrosis, a condition in with pulmonary edema seldom appeared before the fifth day after wounding.

The clinical manifestations of pulmonary edema chiefly took the form of frothy pulmonary secretions in excessive amounts. If right heart failure

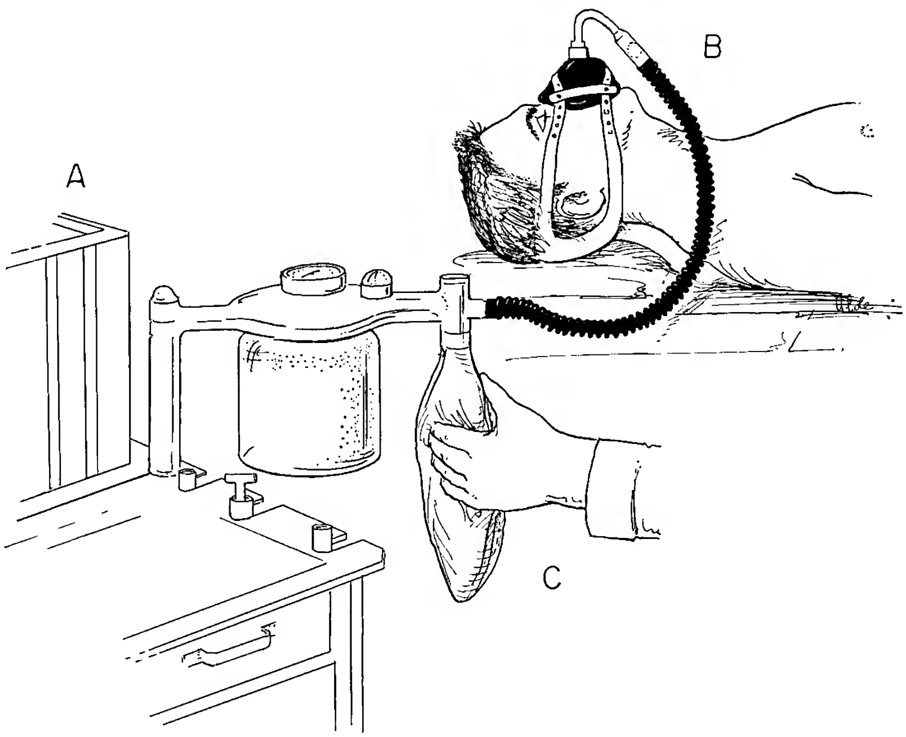

FIGURE 50.—Technique of intermittent positive pressure oxygen administration in field and evacuation hospitals. A. Anesthetic machine with to-and-fro filter. B. Anesthetic face mask, held over nose and mouth by rubber sling. C. Manual compression of bag synchronous with each respiration (pressure 15–20 cm. H_2O).

supervened, the symptoms and signs included: Hyperpnea, distention of the veins of the neck, and falling pulse pressure and systolic pressure.

Since pulmonary edema was usually secondary to some other pathologic process, which often was obscure itself, specific treatment was generally unsatisfactory and often failed entirely. The basis of therapy was an attempt to increase oxygenation, and oxygen given through a mask, under positive pressure (fig. 50), was sometimes distinctly beneficial. Repeated catheter suction was employed to remove the pulmonary secretions. If necessary, a small catheter was left indwelling in the trachea, and oxygen was administered between aspirations. A few patients were benefited by atropine sulfate (gr. 1/100) by vein.

Right heart failure was treated by prompt venesection of from 500 to 750 cc. of blood or by the application of tourniquets (the so-called bloodless phlebotomy). It was difficult to distinguish from shock, but the differentiation had to be made before either measure was instituted.

FIGURE 51.—Postoperative atelectasis with complete collapse of lung. Note tracheal and mediastinal shift.

ATELECTASIS

General Considerations

Massive pulmonary collapse as the result of trauma to the chest, as well as of trauma to the abdomen, might involve all the lobes of one lung but more often involved only one or two. The precise amount of trauma seemed relatively insignificant. Collapse sometimes occurred from the pressure effects of bombs or shells. In such cases, as well as in instances of direct trauma, contrecoup collapse might occur, with only minor involvement of the homolateral side.

The frequent existence, before wounding, of bronchitis and other upper respiratory infections favored the development of atelectasis. Prolonged ether anesthesia also encouraged its development.

Postoperative atelectasis (fig. 51) was infrequent. In this variety, as well as in the traumatic variety, the basic pathologic process was excessive fluid accumulations that completely obstructed a bronchus. The explanation for its very low incidence was the routine and effective treatment of wet lung before and after operation.

Clinically, a patient with atelectasis presented a far greater degree of dyspnea than might be expected from the collapse of a single lobe. Cyanosis, though also more than might be expected, was not so prominent as dyspnea. The trachea was deviated to the side of the collapse, and cardiac dislocation toward the affected side was usual. A sudden rise of temperature, from normal to 103° or 104° F., was typical. Physical examination of the chest revealed the usual signs of a nonaerating lobe or lobes.

Management in Forward Hospitals

It was imperative that atelectasis be treated promptly and vigorously. Persistence of the collapse was likely to result in pulmonary consolidation. Many chest surgeons, in fact, believed that the majority of postoperative pneumonias were preceded by some degree of atelectatic collapse. In this belief, a number of surgeons prescribed sulfonamide therapy as a prophylactic measure against postatelectatic pneumonia.

The treatment of established atelectasis was directed to the same end as the treatment of wet lung; that is, aiding the patient to expel obstructing fluid from the tracheobronchial tree. He was positioned with the involved side up and was made to cough at intervals of 5 to 10 minutes. If coughing was not effective, a curved, semirigid rubber catheter of the Magill type was inserted into the trachea, and sudden suction, of considerable intensity, was instituted. Often, during intubation, the patient coughed strenuously enough to clear out and aerate the involved lobe or lobes. Carbon dioxide inhalations were sometimes used to increase the depth of respiration, and back slapping and blow bottles were also sometimes used.

If these measures were not promptly effective, bronchoscopy was employed, under local anesthesia. No analgesic was applied to the vocal cords or trachea. In a surprising number of cases, aspiration of only small amounts of mucus from the orifices of the bronchi of the involved lobes corrected the atelectasis immediately. As experience increased, and especially as the efficacy of the method came to be appreciated, it became more and more the practice to resort to bronchoscopy without delay when atelectasis of any serious degree was encountered.

Typically, after spontaneous aeration or aeration following active treatment, rales appeared and persisted for several days, in spite of clinical and roentgenologic evidence of satisfactory aeration and the disappearance of dyspnea and cyanosis.

Management in Base Hospitals

Atelectasis encountered in base hospitals was also infrequent. The lobar type was occasionally encountered in the first year of the experience in North Africa and Italy but was seldom observed later. The atelectasis observed in base hospitals was frequently complicated by infection and was practically always the result of inadequate bronchial drainage. This was in contrast to

the atelectasis seen in forward hospitals, in which the important problem was wet lung secondary to trauma and anoxia.

In the base hospital, atelectasis, like tracheobronchitis and pneumonitis, was likely to be present in casualties complaining of pain in the chest wall and the abdomen and in casualties with spinal damage. Under these circumstances, respiration was shallow and cough ineffective. When there was increased secretion of mucus or of mucopurulent sputum in bronchitis, varying degrees of tracheobronchial obstruction occurred, and atelectasis was always a possibility. Catheter suction or bronchoscopy was the correct treatment, supplemented by intercostal nerve block if pain was a feature.

In 338 wounds of the chest treated at the 21st General Hospital, Mediterranean theater, there were 2 deaths directly due to lobular pneumonia, and the same complication played a possible part in a third fatality. No instance of lobar atelectasis was observed after operation, however, because of the vigorous measures routinely instituted to prevent its development.

In the single case of total pulmonary atelectasis observed in this series, a nonspecific type of bronchitis was found by bronchoscopy on the involved side. No real improvement followed standard therapy. Pulmonary tuberculosis was suspected, but it required numerous sputum examinations to establish the diagnosis. In retrospect, it was concluded that in this case, a subclinical pulmonary tuberculosis was activated by the pyogenic infection that was responsible for the pulmonary collapse. The patient had had a normal chest roentgenogram 2 months before he sustained the severe contusion of the chest that led to atelectasis.[1]

HEMATOMA OF THE LUNG

General Considerations

Hematomas of the lung (figs. 52, 53, and 54), which were common, were found in association with all types of chest injuries. The degree of pathologic involvement ranged from simple contusions with small extravasations of blood into the pulmonary interstitium and, to some extent, into the alveoli, to massive interstitial hemorrhage. The latter variety of hematoma was associated with intra-alveolar hemorrhage which involved whole lobes and even the whole lung.

In general, the clinical significance of a hematoma was in direct proportion to the amount of pulmonary parenchymal tissue involved. In the majority of cases, the entity represented nothing more than a roentgenologic finding. In the more severe cases, the process involved sufficient pulmonary tissue to give rise to dyspnea and even to cyanosis.

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[1] So far as is known, active tuberculosis did not occur after any battle injury in the Mediterranean theater, and there is no known instance in which reactivation of arrested disease could be attributed to battle trauma. These circumstances are testimony to the effectiveness of the screening methods used in the selection of combat personnel.

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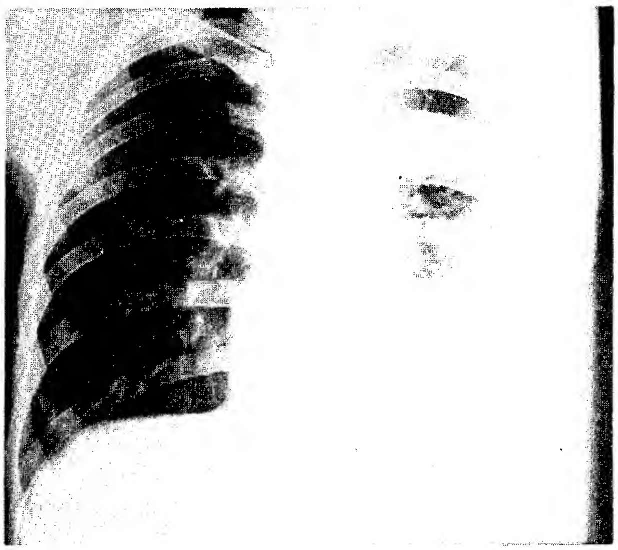

FIGURE 52.—Posteroanterior roentgenogram showing hematoma and clearly defined missile track in left lung. Note foreign body in left axilla.

From a diagnostic point of view, hematomas were occasionally confused with intrapleural collections of fluid or with atelectasis. Thoracentesis and bronchoscopy were frequently required to exclude these diagnostic possibilities. An occasional hematoma was associated with a febrile response and hemoptysis, which might lead the unwary to suspect pulmonary suppuration. The diagnostic confusion might lead, in turn, to the performance of incorrect drainage procedures.

Management

Once the diagnosis of a hematoma was established, the accepted therapy was entirely nonsurgical. No lesion encountered in all the broad spectrum of thoracic trauma demonstrated more dramatically the remarkable recuperative powers of the lung than did massive pulmonary hematomas. As a rule, serial roentgenologic examinations showed slow but steady resolution of the process and complete clearing of the lung.

Hematomas associated with retained foreign bodies of considerable size of course represented a different therapeutic problem, as did those associated with long missile tracks (fig. 52) and with peripheral lacerations. In such cases, operative interference was frequently necessary for removal of the foreign body or closure of the laceration. If a foreign body was present, it was wise to wait for complete resolution of the pathologic process and for stabilization of the patient before an attempt at removal was made.

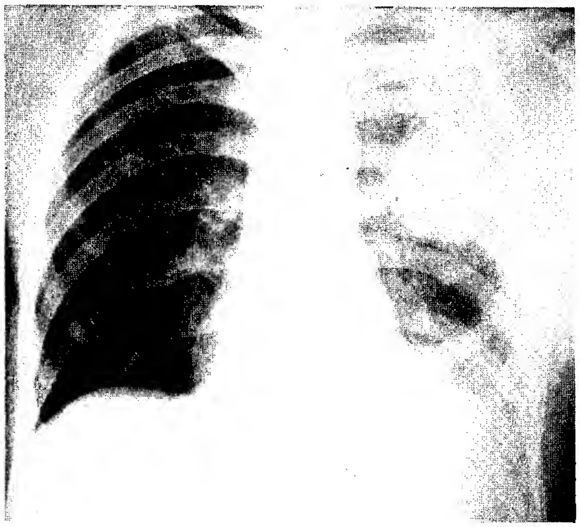

FIGURE 53.—Posteroanterior roentgenogram showing typical intrapulmonary hematoma. Note rounded shadow.

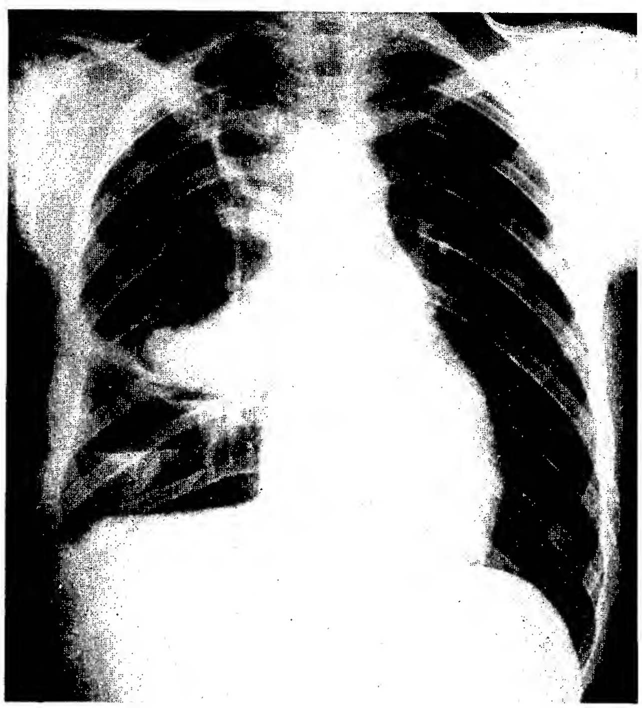

FIGURE 54.—Posteroanterior roentgenogram showing sharply defined intrapleural hematoma.

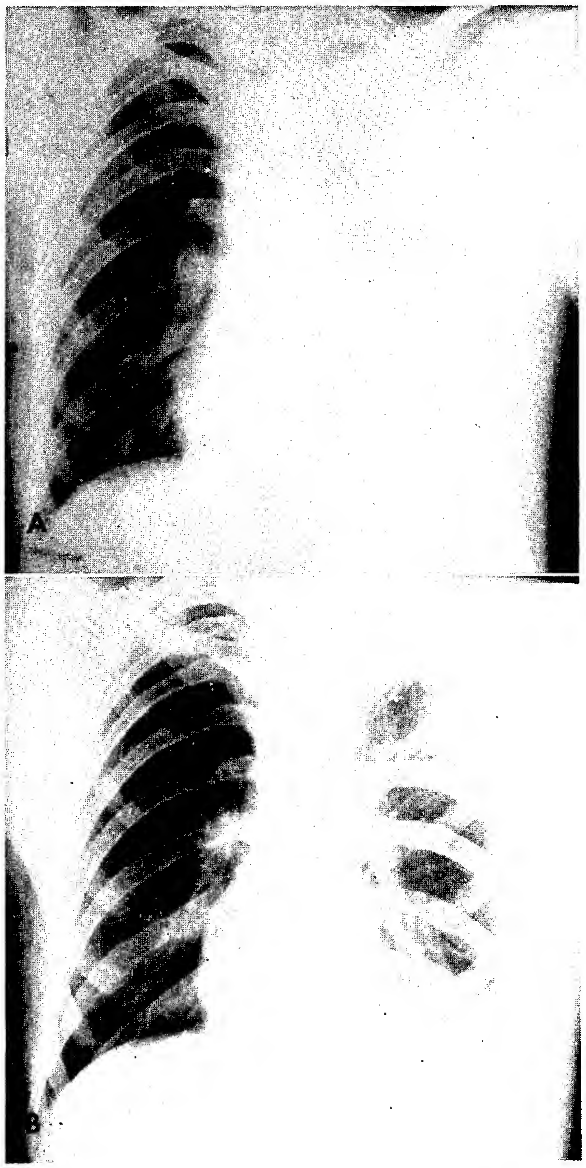

FIGURE 55.—Hematoma of lung. A. Posteroanterior roentgenogram 6 days after wounding showing large hematoma of the left lung. B. Same, 4 weeks later, with only small area of hematoma remaining.

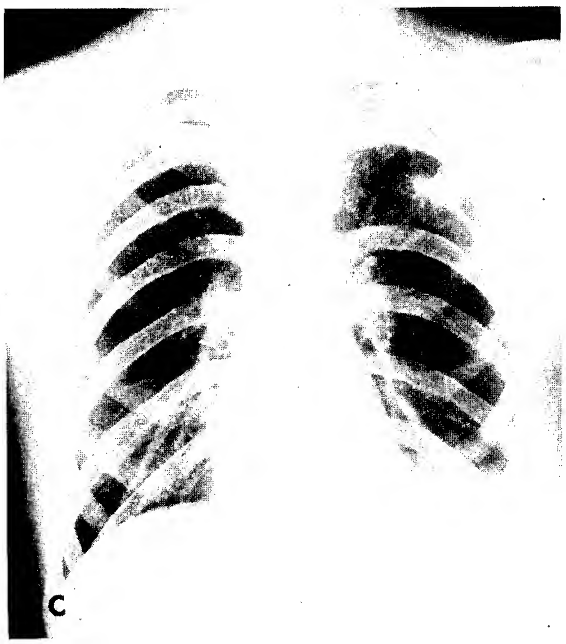

FIGURE 55.—Continued. C. Same, 6 weeks after wounding. Note almost complete disappearance of hematoma.

Case History

The following case history is typical of the progress in most hematomas of the lung:

Case 3.—This patient was wounded on 24 May 1944. A large shell fragment penetrated the left chest and caused a laceration of the lung and a hemopneumothorax on that side. The wound was debrided, the sucking wound closed, and the shell fragment removed from the chest wall. Repeated thoracenteses were performed.

Roentgenologic examination 6 days after wounding showed a large hematoma of the left lung (fig. 55A). Clinically the patient's course was smooth and uneventful. Four weeks after wounding, the hematoma was very much smaller (fig. 55B), and 6 weeks later, roentgenologic examination showed almost no evidence of it (fig. 55C).

BRONCHOPLEURAL FISTULA

General Considerations

Bronchopleural fistulas of traumatic origin were of two types.

In the first group, the fistula occurred without serious parenchymal damage and without pleural infection or significant pulmonary infection. It represented a disruption of the visceral pleura and underlying peripheral lung,

with the establishment of pleuroalveolar or pleurobronchiolar and bronchial continuity, or with both.

These fistulas, which were usually small, might be caused in several ways:

1. By erosion or laceration of the lung from sharp, fixed rib fragments.
2. By the reopening of peripheral lacerations of the pulmonary parenchyma.
3. By the avulsion of the line of repair of a pulmonary laceration that had previously been sutured.
4. By necrosis around metallic foreign bodies or indriven costal spicules.
5. By denudation of lung tissue as the result of its being stripped from an adherent area, either by collapse of the lung because of the accumulation of exudates or transudates or by expansion of the lung after thoracentesis.

In the second group of bronchopleural fistulas, the fistula was part of a serious total situation, and the surgical measures necessary to correct it were part of the major surgery required to care for whatever pleural or pulmonary damage might be present. The procedure most often included drainage of an empyema by rib resection, decortication of the lung (occasionally with segmental pulmonary resection), and, in very occasional instances, drainage of a lung abscess.

Although bronchopleural fistulas were always a potential cause of tension pneumothorax, they were seldom associated with it. A few patients complained of a tight feeling in the chest, but most of them were unaware of what had happened. In a small number of cases observed in the Mediterranean theater, in which the fistulas developed during evacuation from forward to base hospitals, the tension pneumothorax was of considerable proportions, and the patients arrived dyspneic and in generally poor condition. Removal of the air by needle resulted in only temporary relief, but permanent relief of symptoms and prompt healing followed the use of water-seal intercostal drainage.

Diagnosis was made by the discovery of a pneumothorax, either by physical examination or roentgenologic examination, or by both, in a patient whose chest was previously free of pleural air and who had had no breakdown of a chest wall wound to cause an open pneumothorax.

Management

Treatment of bronchopleural fistulas had three purposes: (1) To bring about prompt removal of the air in the chest, (2) to obtain complete reexpansion of the lung, and (3) to close the fistula so that firm and permanent healing would follow. Treatment was instituted as soon as the diagnosis was made.

After manometric determinations of the intrapleural pressure, a small intercostal catheter was inserted under local analgesia and via trocar into the chest at the site of the pneumothorax. Since most bronchopleural fistulas gave rise to apical air pockets, the most usual site of insertion was the second inter-

space in the midclavicular line. The site, however, corresponded with the location of the air pocket, which, because of adhesions, might be restricted to some other portion of the chest. The catheter was connected to a long rubber tube, the end of which was kept under water, to provide closed drainage. This arrangement permitted air to escape from the pleural cavity only when the pressure in it rose above atmospheric pressure. The lung was thus allowed to expand slowly. At the end of 48 hours, and sometimes by the end of 24 hours, the catheter could be withdrawn. If the fistula reopened, as occasionally happened, the catheter was reinserted.

The conservative method of treatment just described was always given a fair trial, even though catheter drainage had to be instituted more than once. It gave very satisfactory results. In 870 penetrating wounds of the chest analyzed by Maj. Thomas H. Burford, MC, from the 2d Auxiliary Surgical Group experience, there were 22 bronchopleural fistulas of the type just described. Twenty-one were closed permanently by the conservative method outlined, though one patient experienced three recurrences of the fistula before solid sealing was obtained. In the remaining case, operation was resorted to after repeated attempts at catheter suction had proved unsuccessful. No patient in the group developed a pleural infection, which is highly significant, since in several instances, the fistula persisted for 2 weeks or more. It was the general experience that fistulas not associated with significant parenchymal damage were not a source of pleural infection if the pleural cavity did not contain blood.

If intrapleural infection did occur, operation was performed at once. Otherwise, thoracotomy for repair of the fistula was not instituted until the full possibilities of thoracentesis and intercostal water-seal drainage had been exhausted.

In some cases, operation was necessary to smooth dangerously sharp rib ends or remove indriven rib spicules or metallic foreign bodies. Only occasionally was it necessary to operate for the fistula alone. This was fortunate, for the difficulties of finding a small fistula at an open operation were often considerable.

The management of bronchopleural fistulas that were a part of other major pathologic processes did not usually furnish problems referable to them alone. Occasionally, however, pressure pneumothorax appeared suddenly in patients with empyema, before dependent drainage had been instituted. Intercostal catheter drainage was instituted at once, by the technique just described.

Case History

A typical instance of bronchopleural fistula treated by the method just described follows.

Case 4.—This soldier, who was wounded in action on 17 September 1944, sustained a perforating wound of the right thorax, with lacerations of the right lung, right diaphragm, and liver. A hemothorax developed promptly. He was treated by thoracolaparotomy,

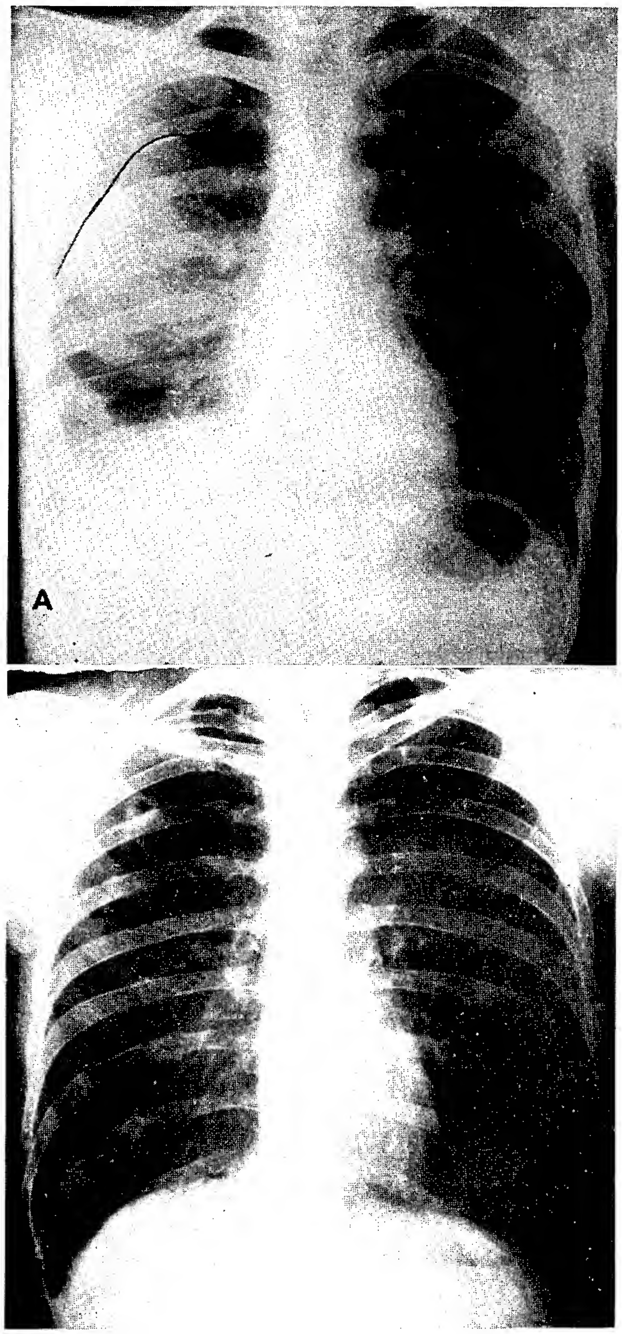

FIGURE 56.—Bronchopleural fistula. A. Posteroanterior roentgenogram showing delayed right bronchopleural fistula with pneumothorax. B. Same, showing complete reexpansion of lung after closure of fistula which occurred 48 hours after insertion of intercostal catheter.

with suture of the diaphragm and subcostal drainage of the hepatic laceration. The pulmonary laceration was not leaking and was therefore not sutured.

The immediate postoperative course was uneventful. Biliary drainage ceased, and the drains were removed. The chest also cleared, but 2 weeks after wounding, the patient began to complain of tightness in the right hemithorax, in which physical examination revealed the presence of air. Roentgenologic examination (fig. 56A) confirmed this finding. Manometric studies also furnished evidence of a small bronchopleural fistula of the right lung.

A small catheter was inserted into the pneumothoracic space, through the second intercostal space in the midclavicular line, and was attached to a water-seal bottle. Twenty-four hours later, the tube had ceased to bubble air. At the end of 48 hours, the water column had ceased to oscillate, and the tube was removed. Examination at this time revealed total disappearance of the pneumothorax and complete reexpansion of the right pulmonary apex. These findings were corroborated by roentgenograms (fig. 56B). The fistula did not recur.

WOUND DISRUPTION

General Considerations

The causes of wound disruption in thoracic injuries and the consequences of the accident are best presented in an analysis of 10 cases observed at the 21st General Hospital in the Continental Advance Section after the invasion of southern France.

The 10 disruptions occurred in 74 sucking wounds, which occurred, in turn, in 338 battle casualties admitted to the thoracic service of this hospital. All but one of the patients had been treated in U.S. Army field hospitals. This man had received his initial treatment in a German hospital.

Analysis of these 10 cases of wound disruption revealed the following data:

1. In eight cases, the damage to the chest wall was severe, and there had been considerable loss of soft tissue.
2. Rib fractures were present in all cases, the number of fractures ranging from one to five.
3. Pulmonary damage was severe in all cases.
4. In two cases, the wound of the chest wall had been contaminated by intestinal contents from a thoracoabdominal wound.
5. Six wounds were in the anterior chest wall, in which muscles are thin and difficult to draw together. Three were located laterally, and the remaining injury was close to the spine.
6. Debridement had obviously been inadequate in the two small wounds in the series and in another large wound, the latter treated at the German hospital.
7. The wound had been left open in two cases. One of these patients had been treated at the German hospital.
8. Thoracentesis had been performed after operation in only three cases.
9. Eight patients had bronchopleural fistulas, bronchitis, and severe wet coughs. In none of these cases had any measures been instituted to improve bronchial drainage.

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10. Empyema was present in every patient, and in only three instances had there been an attempt to drain the pleural cavity. Infection in the pleural cavity and lung, as well as in the chest wall, was thus an important factor in all of these disruptions.

11. In six instances, respiratory embarrassment was the result of mobility of the mediastinum.

12. All but one patient had had penicillin systemically, and at least three had had it intrapleurally also.

Management

When these patients were received in the base hospital, disruption of the chest wound had, in every instance, produced, or reproduced, a sucking wound. Many patients were admitted in severe respiratory distress as a result of the anoxia which had developed during evacuation. Closure of the wound was a secondary consideration in every instance. All the patients needed other treatment far more urgently.

The following treatment was instituted:

1. The wound was occluded with an airtight, petrolatum-impregnated gauze dressing, kept in place by strips of adhesive tape or by an Ace type of bandage. Because of its elasticity, this type of bandage permitted expansion of the lung while at the same time it furnished necessary support to the paradoxically moving chest wall.
2. Intercostal nerve block was carried out if respiration was painful or paradoxical.
3. Oxygen was administered to all patients.
4. Tracheobronchial suction was used if the cough was ineffective.
5. Adequate pleural drainage, which was the keystone of treatment, was instituted as soon as these emergency measures had been carried out.

In six cases, the pleura sealed over without other treatment. In three cases, redebridement was necessary because the wounds contained necrotic muscle tissue. Muscle flaps were developed and the wounds closed in layers with interrupted silk sutures. The remaining patient, whose wound had been secondarily closed at an evacuation hospital, had a second rupture, which was satisfactorily closed by the same measures.

In other words, when the multiple etiologic factors of wound disruption in these 10 cases were under control, wound closure was possible, either by surgical closure or by spontaneous closure of the pleura after satisfactory drainage of the intrapleural infection. The chest wall defect in the latter cases was allowed to heal by granulation, after which the skin edges were drawn together by adhesive tape. With proper initial management, it is doubtful that any of these wound ruptures would have occurred.

CLOSTRIDIAL MYOSITIS

Clostridial myositis was extremely infrequent in wounds of the chest. When it did occur, the etiologic factors and clinical manifestations were essentially the same as in clostridial infections in civil life. The principles of management were also the same.

A point of great importance was that subcutaneous emphysema be clearly distinguished from clostridial infections. The chief point of differentiation was that in emphysema, except in the more extreme cases, air was confined to subcutaneous tissues, while in clostridial infections, it was within the muscle plane.

CHYLOTHORAX

There was no instance of chylothorax in any of the thoracic or thoracoabdominal wounds cared for by surgeons of the 2d Auxiliary Surgical Group. The assumption is that most patients with these injuries died on the battlefield from their severe wounds.

LUNG ABSCESS

Incidence

The incidence of lung abscess in World War II was extremely low. Preliminary figures compiled by the Medical Statistics Division, Office of The Surgeon General, Army, based on sample tabulations of individual medical records (table 10), show only 541 cases for the entire war, 382 in the continental United States and 159 outside of the United States. There were 16 deaths, 10 in the continental United States. Of 255 cases of lung abscess (based on 20 percent sample tabulations of individual medical records) classified as secondary (table 11), 130 occurred outside the continental United States. The figures include both battle and nonbattle cases, and not all of the abscesses secondary to battle wounds were related to wounds of the chest.

The statistical evidence of the infrequency of lung abscess as a complication of battle wounds of the chest supports its infrequency in individual studies and also supports the clinical impression of the World War II chest surgeons. In one analysis of 870 battle wounds of the chest, by Major Burford and eventually included in the total figures of the 2d Auxiliary Surgical Group, there were only 5 instances of lung abscess. Maj. (later Lt. Col.) John Burke, MC, and Capt. (later Maj.) Theodore T. Jacobs, MC, in an analysis of 122 penetrating wounds of the chest at the 23d General Hospital in the European theater, encountered only 2 lung abscesses. Other observers had similar experiences.

The explanation of the infrequency of this complication in battle-incurred wounds of the chest is twofold, (1) penicillin therapy and (2) the intensive efforts immediately after wounding to restore the normal respiratory physi-

TABLE 10.—*Number of admissions* [1] *and deaths* [2] *for lung abscess in the U.S. Army, by area of admission and year, 1942–45*

[Preliminary data based on sample tabulations of individual medical records] [3]

Area	1942–45	1942	1943	1944	1945
	ADMISSIONS				
Continental United States	382	81	132	89	80
Overseas:					
Europe	60	2	8	15	35
Mediterranean [4]	25	1	13	6	5
Middle East	5		5		
China-Burma-India	14	1	2	1	10
Southwest Pacific	24	2	4	13	5
Central and South Pacific	22	1	6	5	10
North America [5]	4	1	2	1	
Latin America	5	2	3		
Total overseas	159	10	43	41	65
Total Army	541	91	175	130	145
	DEATHS				
Continental United States	10	1	7	1	1
Overseas:					
Europe	4	1	1	1	1
Mediterranean [4]	1		1		
Middle East	1		1		
China-Burma-India					
Southwest Pacific					
Central and South Pacific					
North America [5]					
Latin America					
Total overseas	6	1	3	1	1
Total Army	16	2	10	2	2

[1] It is estimated that virtually none were CRO (carded for record only) cases. For the 2 years, 1943 and 1945, in which the number of CRO cases was known, the 320 admissions included but 1 CRO case.

[2] Underlying cause of death; year of death.

[3] Complete files of records used for deaths, 1942 admissions, and oversea admissions in 1943. Samples of admissions were: 20 percent for 1945, U.S. 1943, and Europe 1944; 80 percent for 1944, excluding Europe.

[4] Includes North Africa.

[5] Includes Alaska and Iceland.

TABLE 11.—*Number of secondary cases [1] of long abscess in the U.S. Army, by area and year, 1944–45*

[Preliminary data based on 20 percent sample tabulations of individual medical records]

Area	1944–45	1944	1945
	Number	*Number*	*Number*
Continental United States	125	75	50
Overseas:			
Europe	60	15	45
Mediterranean [2]	20	15	5
Middle East			
China-Burma-India			
Southwest Pacific	45	20	25
Central and South Pacific			
North America [3]			
Latin America	5		5
Total overseas	130	50	80
Total Army	255	125	130

[1] Battle and nonbattle cases.
[2] Includes North Africa.
[3] Includes Alaska and Iceland.

ology. Since lung abscesses were infrequent even before penicillin became available in the spring of 1944, the second of these explanations must be considered the more important.

The low incidence of lung abscess can also be interpreted as further evidence of the remarkable recuperative capacity of the lung, particularly when, as just mentioned, its inherent capacity was supported by prompt measures to assure a patent airway and total pulmonary reexpansion. Consistent with the infrequency of localized intrapulmonary suppuration was the observation that bacteria were seldom cultured from missile cavities when foreign bodies were removed in uncomplicated cases (p. 327).

There was no explanation, however, of why pulmonary abscesses developed about an occasional foreign body and not about others. One explanation advanced was that while the heat of shell fragments might be sufficient to sterilize most pathogenic bacteria, bits of clothing driven into the lung along with the missile might carry infecting micro-organisms in with them. This is not an acceptable theory, partly because this occurrence was so frequent and lung abscesses so infrequent, and partly because the infecting micro-organisms found in lung abscesses were usually resident respiratory flora. The number of cases is too small to permit anything beyond the mere statement of facts, but it might be mentioned that the abscess formed about a foreign body with recognizable bits of cloth attached to it in three of the five cases reported by Major Burford. Other, isolated observations were to the same effect.

Management

The type of lung abscess seen in battle-incurred injuries differed from the type seen in civilian practice. In civilian practice, the abscess begins with a diffuse area of pneumonitis, and, if progress is favorable, as it usually is, the process proceeds to localization. In the traumatic type of abscess, the localized phase was the first phase. This was a distinction of fundamental importance from the standpoint of treatment: In the traumatic type of abscess, the earlier the attack, the simpler the procedure, and the better the results.

In four of the five cases studied by Major Burford, the abscess was excised, the excision including the foreign body in the three cases in which the missile was retained. Drainage was instituted in the remaining case. All five patients eventually recovered, though in two instances, the abscess recurred and required secondary drainage. Drainage of an associated empyema was necessary in both of these cases.

Penicillin therapy and the intelligent use of whole blood were important parts of the routine of management, but good surgery was the basis of treatment.

Massive gangrene of the lung was not observed by surgeons of the 2d Auxiliary Surgical Group, but in two instances, extensive suppuration developed, apparently on the basis of extensive vascular damage. The process in both cases went on to multilobar areas of pneumomalacia with multiple bronchopleural fistulas and widespread pleuropulmonary sepsis. One patient recovered after multiple drainage operations. The other died after total pneumonectomy.

MEDIASTINAL ABSCESS

Surgeons of the 2d Auxiliary Surgical Group encountered abscess formation of the anterior mediastinum in only one instance. The infection developed about a retained foreign body, and the organism recovered was a pure strain of hemolytic streptococcus. Complete and prompt recovery, without complications, occurred after thoracotomy, removal of the foreign body, evacuation of the abscess, and intrapleural instillation of penicillin.

An occasional patient was observed in forward hospitals with localized abscesses of the posterior mediastinum or diffuse posterior mediastinitis. These infections were considered the only indication for posterior extrapleural mediastinotomy in war wounds of the thorax. None of this small group of patients survived to reach base hospitals.

PNEUMONITIS AND PNEUMONIA

Infectious pulmonary complications, chiefly pneumonitis and the pneumonias, were considerably more infrequent in chest injuries than had been expected, in view of the World War I experience. The low incidence, which was

practically the same in thoracic and thoracoabdominal wounds, could be explained in several ways:

1. The attention devoted to the correction of wet lung both before and after operation. Measures that drastically reduced the incidence of atelectasis, as the correction of wet lung and maintenance of a patent airway reduced it, also drastically reduced the incidence of pneumonitis and subsequent pneumonia.
2. The postoperative routine which emphasized coughing, frequent turning in bed immediately after operation, and early ambulation.
3. Perhaps the unwitting prophylaxis instituted by the administration of sulfonamides and later of penicillin as part of the routine of management of all wounds.

Pneumonitis almost always developed on the basis of atelectasis or of stagnation of excessive bronchial fluids. Pneumonia was more frequent in the winter months, when it was often superimposed on a preexisting purulent bronchitis. An occasional lobar pneumonia was a primary pathologic process.

Diagnosis of pneumonitis and pneumonia was by the usual symptoms and signs (toxicity, increased fever, pulmonary consolidation) supplemented by roentgenologic examination.

Sulfadiazine was the drug of choice. It was frequently observed that a pneumonia that had developed under penicillin therapy responded promptly to sulfonamide therapy. If stagnation of bronchial secretions was a persistent feature of the disease, and if the patient could not or would not cough effectively, either catheter suction or bronchoscopy was employed, even when pulmonary infection was clearly established. No undesirable consequences followed this practice.

Atelectasis and pneumonia caused by inadequate bronchial drainage were fairly common on neurosurgical and general surgical wards. The staffs of the thoracic surgical wards saw many of these patients in consultation and assisted in their care, particularly in the performance of catheter suction and bronchoscopy.

TRAUMATIC OSTEOMYELITIS

Neither osteomyelitis nor osteochondritis was frequent after trauma in World War II, in contrast to their relative frequency in World War I. Both were managed by removal of the involved segments under systemic penicillin protection. The wound was left widely open for 4 to 10 days. Then secondary suture or staged closure was carried out, depending upon the rapidity with which the wound cleared up. To await sequestration of the bone was not in harmony with modern surgical principles.

Osteomyelitis of the scapula was seen at least 10 times more frequently in the early fighting in North Africa than later. The explanation was that in

the early months of the war, debridement about the scapula was not sufficiently radical. Later, there was a better realization of the importance of adequate initial wound surgery. Free incision with removal of sequestra usually resulted in prompt cure.

CHRONIC SINUSES OF THE CHEST WALL

General Considerations

Chronic sinuses of the parietes were encountered in a small number of patients in the base area and in a larger number in Zone of Interior hospitals. The causes were chiefly as follows:

1. Injury to the costal cartilage, caused by the so-called gutter type of wound, with destruction of the cartilage as a result. Sinuses of this origin continued to drain until all diseased cartilage had sloughed off, or, better, had been excised.

2. Retained foreign bodies. Sinuses were particularly frequent when bits of clothing or other foreign organic material had collected around retained metallic fragments, but metallic fragments alone could be responsible for the sinuses.

3. An unwise selection of suture material. In closing particularly large defects of the chest wall, it was sometimes necessary to use pericostal or perichondral sutures to pull the ribs and cartilages together. Experience proved that the use of heavy silk or wire or other nonabsorbable suture material was unwise; healing was sometimes satisfactory, but many times these materials acted as retained foreign bodies. As the war progressed, pericostal and perichondral sutures were not used if they could be avoided. If they could not be avoided, absorbable suture material was used.

4. Un-united fractures or fractures that had healed with excessive scar tissue and callus formation. These were infrequent causes of parietal sinuses and were seldom an indication for surgery.

5. Osteomyelitis of the ribs or other bones (fig. 57).

Management

The basis of management of these sinuses of the chest wall was the removal of the offending retained material, whatever it might be. The removal of retained foreign bodies and unabsorbed suture material offered no difficulties. If bone or cartilage was responsible for the sinus, the infected area was excised. Numerous exceptions were noted to the opinion that infection involving cartilages in the fused portion of the thoracic cage requires complete excision of the involved fused cartilage for permanent cure. As experience accrued, it was found that a less radical resection, involving only the infected segment,

FIGURE 57.—Sinus of chest wall resulting from traumatic osteomyelitis of clavicle. Note swelling of tissues just below pointer.

was all that was necessary in most cases. If there was a recrudescence of the infection, the more radical operation could be done as a secondary procedure.

At operation, the wound was opened widely and the offending material removed. The extent of the debridement depended upon the circumstances in the individual case. Since all of these wounds were infected, the skin and subcutaneous tissues were left open, as at initial wound surgery. Secondary closure of the incision was usually possible under penicillin protection from 5 to 7 days later.

DEFECTS OF THE CHEST WALL

Wounds causing large defects of the chest wall were frequent. They reflected, in a dramatic fashion, the effectiveness of modern weapons. They were also observed frequently because adequate debridement of an initially large wound resulted in a sizable opening in the chest wall. This was particularly true at Anzio, where many patients with large traumatic thoracotomies would

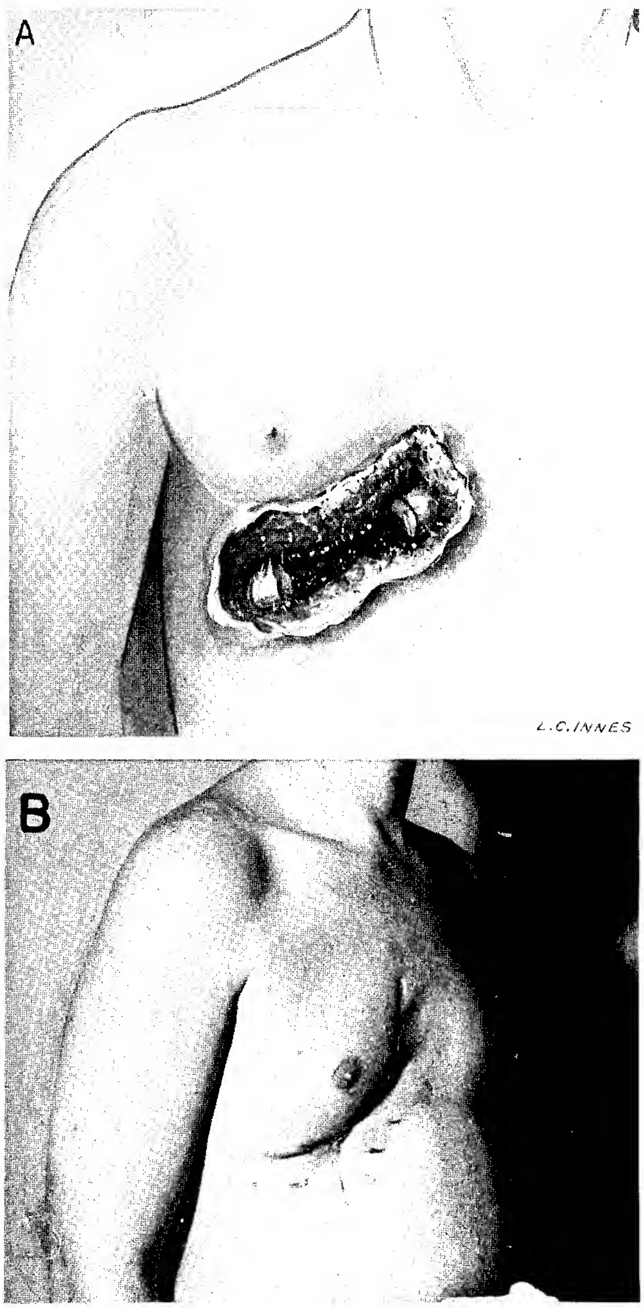

FIGURE 58.—Defect of anterior chest wall. A. Large defect, with typical loss of substance, sketched before debridement. B. Result 1 month after repair of defect by swinging down small muscle flap from pectoralis major. This picture was taken 7 days after delayed primary wound closure in a base hospital. The patient recovered uneventfully. Note absence of lung hernia.

not have survived except for immediate surgery in hospitals close to the frontlines.

These large defects presented special problems of management. The necessary intrathoracic procedures were carried out with dispatch, particular attention being paid to removal of fragments of ribs and clothing, which were found more often, and in larger amounts, than in any other type of chest wound. Debridement had to be even more thorough than usual, because it was often advisable to close the skin primarily, to enhance the security of repair.

Satisfactory restoration of the chest wall often required patience and ingenuity. The procedures utilized to accomplish closure without dangerous tension varied with the number and location of the defects. Pericostal sutures, though generally undesirable, had to be used in some cases to approximate the ribs and thus reduce the size of the defect. In flail segments of the ribs, it was occasionally feasible to use wire to fix the ends. Muscle flaps were very useful, particularly in the anterior chest (fig. 58), in which tissues for repair were sparse. The paraspinalis group of muscles was used for flaps low in the posterior chest, where there was a similar paucity of tissue. In an occasional case, the subscapularis was used, as suggested by Maj. (later Lt. Col.) Reeve H. Betts, MC, and Capt. (later Maj.) William M. Lees, MC, with the arm positioned to bring the scapula over the opening. If nothing else was possible, closure was effected by reattachment of the hemidiaphragm.

ADHESIVE PLEURITIS

Pathologic Process

Deforming adhesive pleuritis, also known as infolded lung, was a fairly common complication of chest injuries. Its mechanism was not clearly understood but could be postulated as follows:

1. The blood present in the pleural cavity after wounding resulted in compression of the lung.
2. The lung was additionally compressed by an associated pneumothorax.
3. If the pleural blood clotted, it occupied a considerable portion of the pleural space.
4. In the simplest type of infolded lung (fig. 59), as a result of the thoracic wound, the associated hemothorax, and the resulting deflation of the lung, the diaphragm was elevated and splinted. The costophrenic fringe of the lung was dragged along the dome of the diaphragm and presumably became retracted. Since blood was invariably present in some amount in all thoracic wounds, symphysis occurred between the costophrenic fringe of the lung and the diaphragmatic pleura at what might be termed the high watermark.
5. Eventually, as the result of absorption of air, or of aspiration of blood or air, or of both processes, the lung began to reexpand, filling the pleural space that remained by rolling out over the area of the pleural symphysis and expand-

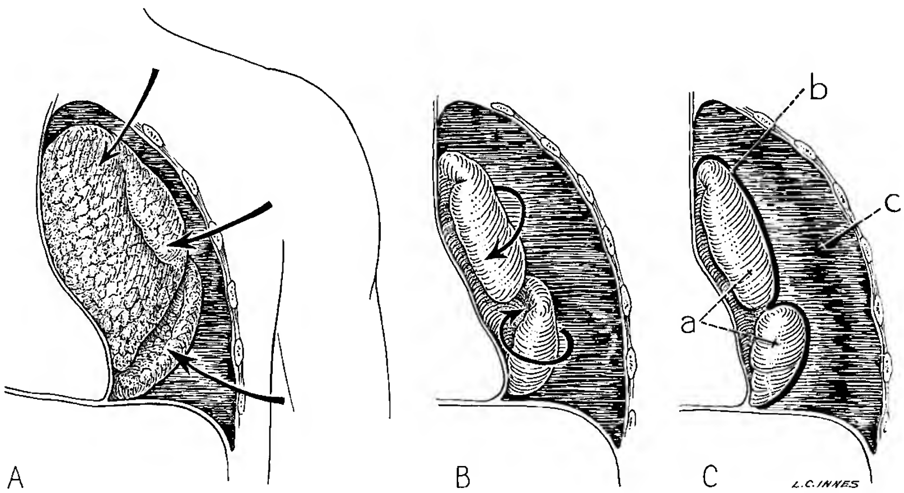

FIGURE 59.—Diagrammatic representation of infolded lung (adhesive pleuritis). A. Rapid massive intrapleural hemorrhage. B. Lung infolding as it is compressed by massive bleeding. C. Captive infolded lung (a), held by pleural membrane (b), resulting from organizing hemothorax (c).

ing those portions of its contour that could most conveniently occupy the available space. The upper portions of the lung were free to expand and fill the apex of the chest. The peripheral portion of the base could be filled only by adaptation of the lung to the available space.

The process just postulated furnished a satisfactory explanation for slight degrees of pulmonary infolding. They were of no great clinical significance, and they probably occurred much more often than they were recognized. On the other hand, extensive degrees of infolding and distortion were serious. They sometimes occurred as the result of adhesions between the visceral and parietal pleural coats or between opposed portions of the visceral pleura (fig. 59). Bizarre distortions were occasionally observed, as the result of a symphysis between the lateral costophrenic fringe and the mediastinum, along its diaphragmatic border.

Though the mechanism of infolded lung was not clearly understood, the consequences were evident. Because the hemithorax was not completely filled by the lung, areas within it that were not adequately filled by lung tissue were likely to be filled by recurrent accumulations of pleural fluid. This fluid, after the blood in the chest had been removed, was uniformly serous. It formed only in small amounts, but it had a tendency to reaccumulate after it was removed by aspiration.

If the adhesive process involved large areas of lung, pulmonary expansion was considerably slower than when an uncomplicated hemothorax was present, and filling of the hemithorax was considerably delayed. These observations

explained the contracture of the chest wall observed in such cases; it was merely Nature's attempt to reduce the size of the hemithorax.

Some degree of infolding was uniformly seen in association with massive intrapleural clotting. Most observers thought that if roentgenologic examination showed obscuration shortly after wounding and showed clearing within a period of weeks of expectant treatment and vigorous breathing exercises, the patient had had an infolded lung and not an organizing hemothorax. An organizing hemothorax was likely to be irreversible without more active therapy.

Diagnosis

The only condition easily confused with deforming adhesive pleuritis was organizing hemothorax. The differentiation was extremely important: An organizing hemothorax of any extent constituted a definite indication for thoracotomy and decortication; an infolded lung did not.

The differentiation was usually readily accomplished by roentgenologic examination, but certain clinical features were also helpful. In organizing hemothorax, but not in infolded lung, the physical findings usually included dullness on percussion over the affected area; decreased tactile fremitus; suppression of breath sounds; narrowing of the interspaces; and possibly retraction of the mediastinum toward the affected side, with elevation and relative immobility of the corresponding hemidiaphragm. Blood was usually obtained by thoracentesis.

Roentgenograms taken in infolded lung showed a generalized obscuration of the pleural space in the posteroanterior projection. In lateral films, there was a triangular posterior obscuration generally regarded as typical of the process. The opacity was produced by the infolding and malaeration of the affected pulmonary area, as well as by the small, irregular, and usually intercommunicating collections of pleural fluid. It was the findings in the lateral roentgenograms which differentiated adhesive pleuritis from organizing hemothorax. In the former, the obscuration was patchy and diffuse because the process was not localized. In the latter, the opacity was posterior and basal.

Management

If within 3 or 4 weeks after wounding, an infolded lung had expanded sufficiently to fill the hemithorax, expectant treatment was continued. Even though the chest was somewhat contracted, it was thought that return of function to the chest wall by the practice of breathing exercises would eventually correct the deformity. Conservative management was indicated whenever serial roentgenograms showed that pulmonary reexpansion had been shared proportionately by all the lobes, so that the patient would not be left, for example, with a fully expanded upper lobe and a seriously contracted lower lobe.

On the other hand, release of limiting adhesions by surgery was considered justified if, within 3 or 4 weeks after wounding, the lung had not expanded

sufficiently to fill most of the hemithorax or if serial roentgenograms showed that the filling had been accomplished predominantly by one portion of the lung at the expense of other portions. In most cases, though not in all, when filling of the hemithorax was long delayed, it was much more likely that failure of pulmonary expansion was the result not so much of infolding of the lung, even if it was present to some degree, as of compression of the lung by the peel or rind of an organizing hemothorax. In that type of case, decortication of the lung was clearly indicated.

DIAPHRAGMATIC HERNIA

Up to 1944, the Medical Statistics Division, Office of The Surgeon General, Army, coded diaphragmatic hernia with a residual group of hernia conditions. The data for 1944 and 1945, when diaphragmatic hernia was coded separately, show a total of 449 cases and 9 deaths (table 12). In 230 cases, diaphragmatic hernia was the secondary diagnosis.

Data on deaths were obtained from a complete file of records. Admissions in 1945 and for the European theater in 1944 were derived from a 20-percent sample of records. Admissions in 1944 for areas other than the European theater were derived from an 80-percent sample. Data on secondary diagnoses were derived from a 20-percent sample. Not all of the hernias associated with battle-incurred wounds were related to wounds of the chest.

Oversea Experience

The small samples from which the statistics just cited are derived do not permit generalizations. They are in correspondence, however, with the impressions of surgeons both overseas and in the Zone of Interior that traumatic diaphragmatic hernias were decidedly infrequent. Only 2, for instance, were observed in 1,028 intrathoracic wounds analyzed by Major Burford from the 2d Auxiliary Surgical Group experience.

In the first of these cases, the hernia was not suspected before thoracotomy, which was undertaken for removal of a missile from the left lower pulmonary lobe. In the second case (fig. 60), which was not a combat injury, the casualty sustained a crushing injury to the upper abdomen when a jeep was blown off the road, by the explosion of a mortar shell, and was overturned. Early thoracotomy revealed that the stomach and colon had herniated through a large tear in the left leaf of the diaphragm. The tear extended to, but not through, the left crus of the hiatus. Convalescence was uncomplicated, and postoperative roentgenologic examination showed normal configuration of the diaphragm and stomach. Both of these patients were returned to duty in the theater.

So far as is known, no instance of diaphragmatic herniation was observed in the Mediterranean theater in a battle wound in which the diaphragm had been sutured. The early experience had demonstrated the risk of suturing the

TABLE 12.—*Number of total cases (incidence), admissions, secondary diagnoses, and deaths from diaphragmatic hernia [1] by area of admission and year, 1944–45*

[Preliminary data based on sample tabulations of individual medical records]

Area	Incidence [2]	Admissions [3]	Secondary diagnoses [4]	Deaths [5]
	1944			
Continental United States	146	86	60	4
Overseas:				
Europe	40	10	30	
Mediterranean [6]	18	8	10	
Middle East	9	4	5	1
China-Burma-India				
Southwest Pacific	18	3	15	
Central and South Pacific	3	3		
North America [7]				1
Latin America	5		5	
Total overseas	93	28	65	2
Total Army	239	114	125	6
	1945			
Continental United States	115	70	45	2
Overseas:				
Europe	40	5	35	
Mediterranean [6]	15	5	10	
Middle East				
China-Burma-India	5		5	
Southwest Pacific	20	10	10	
Central and South Pacific	10	10		1
North America [7]	5	5		
Latin America				
Total overseas	95	35	60	1
Total Army	210	105	105	3

[1] Battle and nonbattle cases.
[2] Sum of admissions and secondary diagnoses.
[3] Cases in which diaphragmatic hernia was the primary cause of admission to a medical treatment facility.
[4] Cases of diaphragmatic hernia secondary to, or concurrent with, some other admission diagnosis.
[5] Underlying cause of death, year of death, and theater of admission.
[6] Includes North Africa.
[7] Includes Alaska and Iceland.

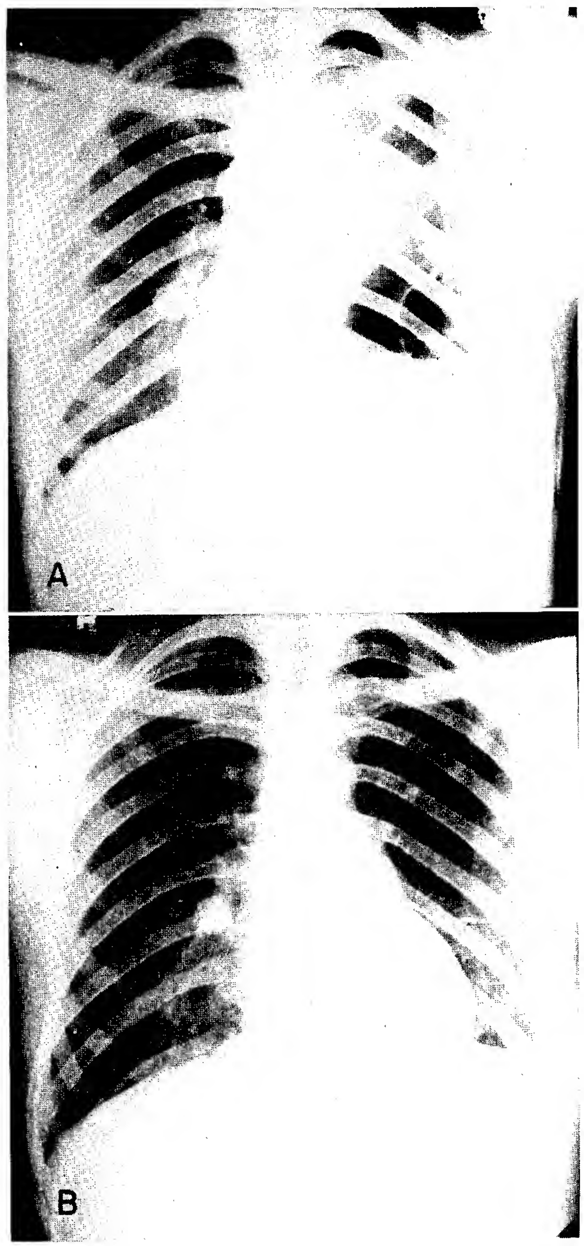

FIGURE 60.—Traumatic diaphragmatic hernia. A. Posteroanterior roentgenogram 4 hours after crushing injury of lower chest and upper abdomen. At operation, both stomach and large bowel were found in chest. B. Same, 10 days after thoracotomy, reduction of hernia, and repair of diaphragm.

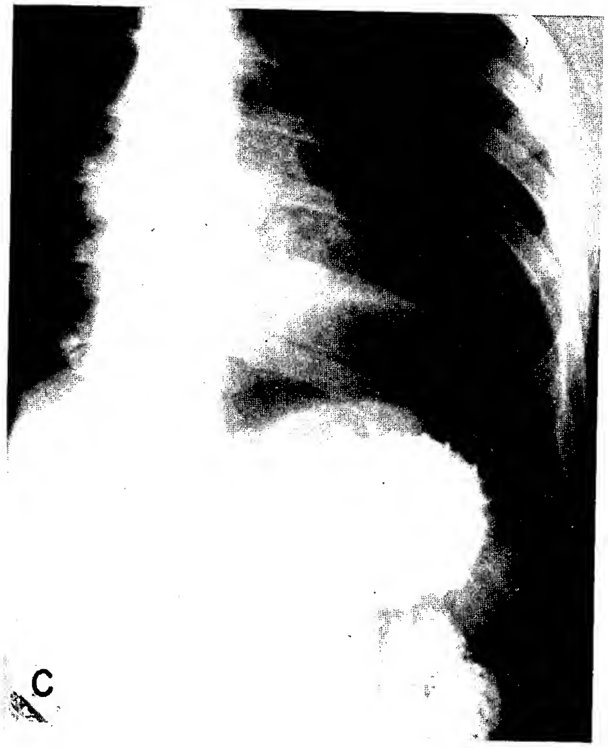

FIGURE 60.—Continued. C. Detail film after barium meal demonstrating normal stomach pattern and intact diaphragm. Patient made an uneventful recovery.

diaphragm with catgut whenever there was any risk of bile leakage. Sutures of silk, cotton, or nylon held consistently. Bile, free of its normal confines, always makes trouble, and the success of diaphragmatic suture was in large part due to recognition of this fact and provision of adequate drainage for a sufficiently long period (p. 118).

Zone of Interior Experience

Diaphragmatic hernia of traumatic origin was seen only slightly more frequently in the Zone of the Interior than overseas. The 28 patients observed at the Kennedy General Hospital chest center, Memphis, Tenn., during the 3-year period of its operation may be taken as typical, and the analysis of these cases is the simplest method of presenting the main points in the clinical picture and management of this condition.[2]

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[2] This analysis was made by Maj. Felix A. Hughes, Jr., MC; Maj. Earle B. Kay, MC; Lt. Col. Richard H. Meade, Jr., MC; Maj. Theodore R. Hudson, MC; and Maj. (later Lt. Col.) Julian Johnson, MC. All of these officers served at various times in the thoracic surgery center, Kennedy General Hospital.

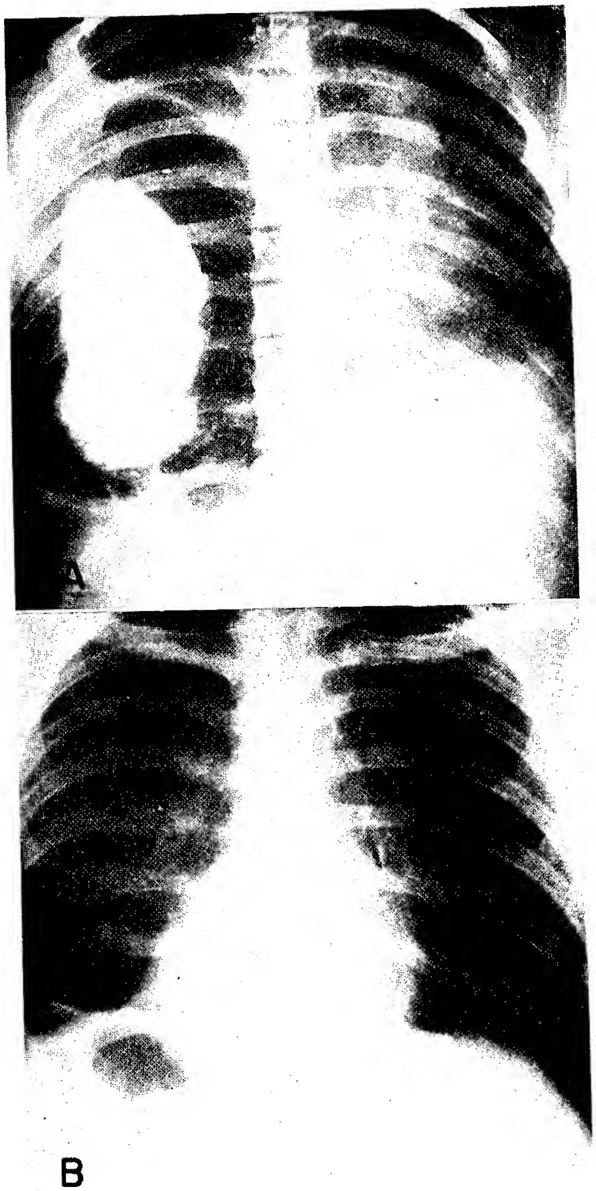

FIGURE 61.—Diaphragmatic hernia. This patient, a prisoner of war, was injured in France in 1944, and then worked in the United States for a year without symptoms. A. Posteroanterior roentgenogram made after onset of symptoms induced by carrying heavy sacks. The greatly distended stomach, partly filled with barium, occupies the left pleural cavity. B. Same, after reduction of hernia and repair of diaphragm. Recovery was uneventful.

Etiology and pathogenesis.—In 16 of the 28 cases, the wounds were caused by shell fragments, or machinegun, rifle, or pistol bullets. In the remaining 12 cases, the hernias, which were not combat-incurred, were variously caused or precipitated by traffic accidents (9), a stab wound, a fall, and jumping from a truck. In five of the combat-incurred hernias, the injured diaphragm had been repaired overseas at the time of wounding.

In the 11 combat-incurred wounds in which the diaphragm had not been repaired overseas, the defect was so small that no herniation occurred until sudden strain or prolonged strain caused it to enlarge. One soldier, for instance, had sustained a penetrating wound 13 months before, for which thoracotomy was not considered necessary. Suddenly, while carrying heavy sacks, he was seized with severe upper abdominal pain. At operation, the entire stomach was found in the chest (fig. 61). Another patient had sudden, acute symptoms after he jumped from a truck. At operation, the colon was found herniated through a defect only 1.5 cm. in diameter, and gangrene had already set in. Three other patients with known hernias of several months' duration also developed acute intestinal obstruction while under observation in the hospital. Emergency operation was successful in all three cases.

The first patient with a diaphragmatic hernia observed at the chest center at Kennedy General Hospital furnished a useful lesson. He had sustained a bullet wound of the right chest in May 1943. A few weeks later, he showed no abnormalities of any consequence on roentgenologic examination (fig. 62A) and had no symptoms of any kind. He continued well for a year. Then he began to complain of pain in the right lower chest, and roentgenograms showed a rounded mass overlying the diaphragm (fig. 62B). Exploratory thoracotomy was performed, and the mass was found to be a herniated portion of the right lobe of the liver. Undoubtedly, many cases of this kind have been observed in veterans' hospitals and in private practice since the war. If there is no hemorrhage, gangrene, or perforation of the gastrointestinal tract, patients may accustom themselves to living with a surprising degree of diaphragmatic herniation.

In no instance was it possible to correlate the hernia, either in size or location (fig. 63), with the anatomic areas of weakness in which such hernias are prone to occur. Obviously, however, increased abdominal pressure, produced by strain, as a number of cases in this series show, may be the immediate cause of herniations through previously created defects, even when the defect is small.

Pathologic process.—A definite sac was demonstrable in only two of the hernias in the series. A membrane frequently covered a part of the herniated structure, but it was not complete. The adhesions present in practically all cases between the affected structures varied in extent and character. At times, it was impossible to separate the herniated structures from the lung without some pulmonary damage. The size of the opening in the diaphragm varied from a defect 1.5 cm. in diameter to one that involved the entire dome and extended into the pericardium.

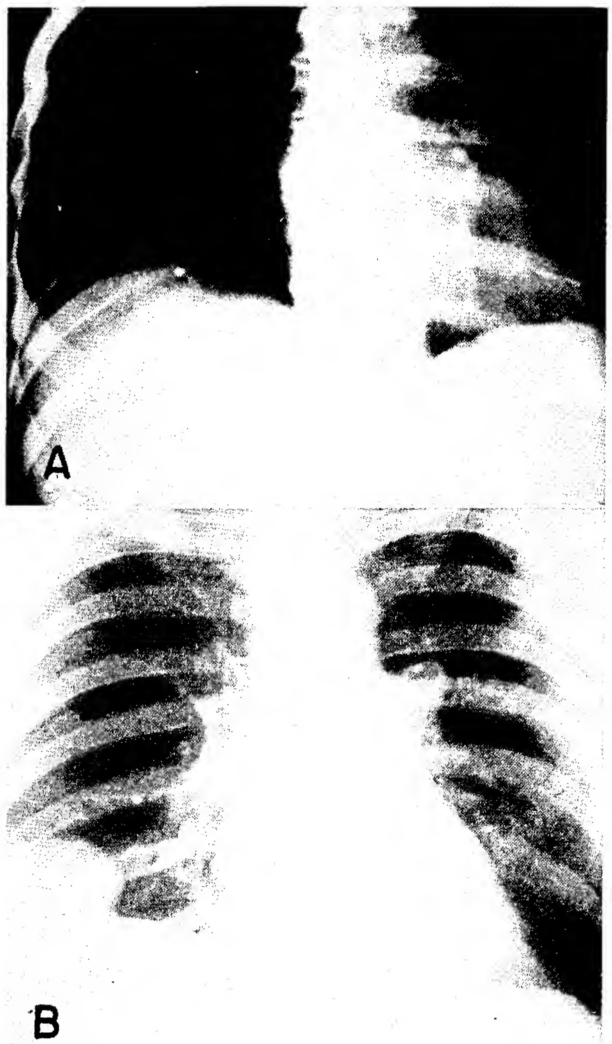

FIGURE 62.—Diaphragmatic hernia. A. Posteroanterior roentgenogram 4 months after penetrating wound of right chest. There is no evidence of herniation in this film, and the patient was asymptomatic. B. Same, 1 year later, showing herniation of right lobe of liver.

The dome of the left diaphragm was the site of the hernia in 12 of the 28 cases (fig. 63). Contusion defects were located more peripherally and penetrating defects more centrally.

At operation, practically all the organs in the peritoneal cavity were found herniated through the diaphragm, either singly or in various combinations. At one extreme were asymptomatic herniations of the omentum, discovered accidentally at operation for other conditions. At the other extreme were two herniations, each consisting of the kidney, spleen, stomach, small bowel, colon, and omentum. In one of these cases, the structures were densely adherent and completely covered the lateral portion of the diaphragm. In the other, there was an 8-inch tear in the pericardium.

In one case, there was a constricting ring defect around the herniated stomach (fig. 64); if diagnosis had been delayed, ischemic changes, followed by perforation, would undoubtedly have ensued. In one instance, in which previous repair had been done elsewhere, the diaphragm had been severed from its attachments to the posterior chest wall, and a hydronephrotic, congenital bifid kidney had herniated through the defect. It was necessary to mobilize and remove the kidney before repair could be accomplished.

In one case, incarceration of the stomach resulted in progressive gastric distention, and eventually the entire left pleural space was filled with the herniated organ, the lung on that side being completely atelectatic. After the defect in the diaphragm had been enlarged, it was possible to express the air from the stomach through the nasal tube inserted before operation. When this had been accomplished, the adhesions could be separated and the hernia reduced.

Clinical picture and diagnosis.—Herniation of solid viscera was associated with vague pain in the lower chest but usually with no other symptoms. Herniation of hollow viscera gave rise to more varied symptoms. In 11 cases, all of combat origin, the initial symptoms were epigastric pain, especially after meals and during recumbency; flatulence; indigestion; and dyspnea, which was practically always present when there was considerable collapse of the lung. Several patients stated that they could hear and feel gurgles in the chest.

If a hollow viscus suddenly herniated through the diaphragmatic defect, the symptoms were more dramatic. In two instances, unconsciousness occurred, not to be accounted for by associated injuries. The degree of pain and the presence of nausea and vomiting depended upon the extent of the herniation and the amount of obstruction it produced.

In some cases, as already mentioned, herniation of the omentum through the diaphragm was discovered unexpectedly, at operation for other conditions. In the four cases in which the liver was the herniating organ, only a presumptive preoperative diagnosis was possible. In one of these cases, the herniation, which was recurrent, was found in the course of exploration of a draining sinus of the chest wall. In two cases, the chest was aspirated, in the belief that the fluid in the herniated stomach and intestines was pleural fluid. No evidence of damage or infection was found at operation in either case.

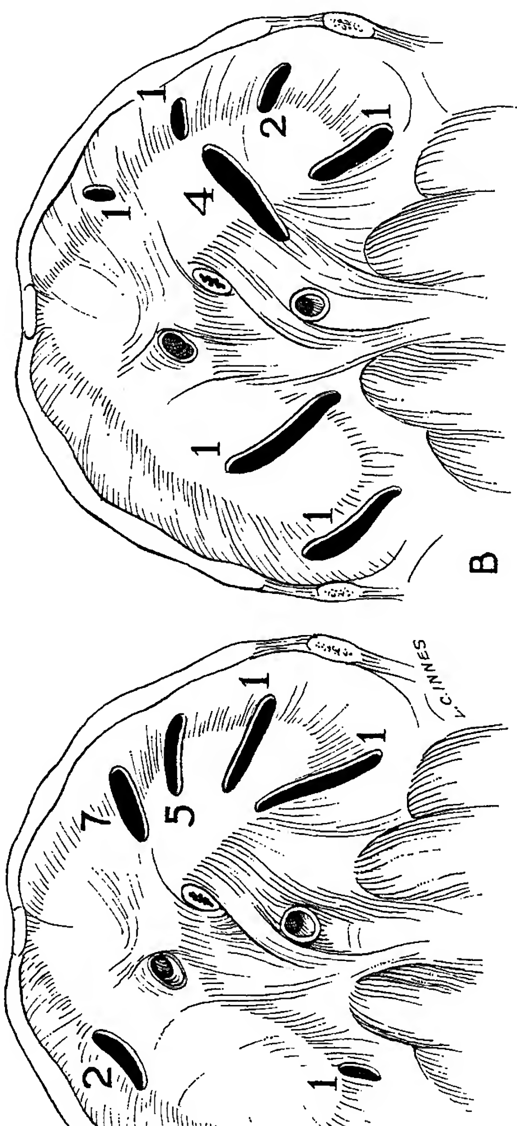

FIGURE 63.—Anatomic distribution of 28 diaphrammatic hernias. A. Location of 17 hernias after penetrating chest wounds. B. Location of 11 hernias after contused chest wounds.

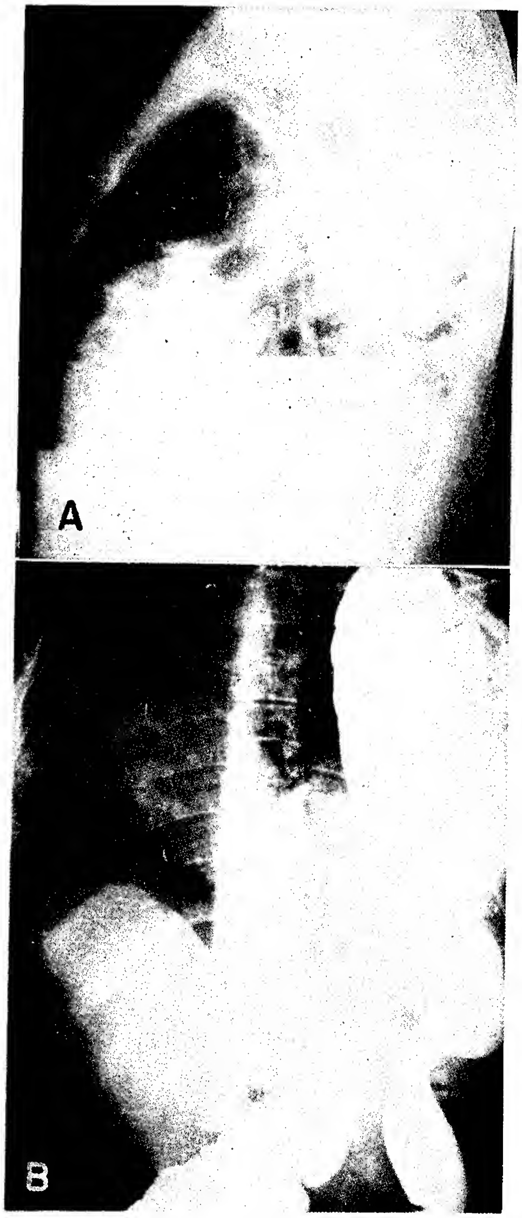

FIGURE 64.—Diaphragmatic hernia. This hernia was found after a forced march with a heavy field pack overseas; it may have originated in an automobile accident several years earlier. A. Posteroanterior roentgenogram showing hernia. B. Same, showing herniated, barium-filled stomach. Note constricting ring.

Surgical repair.—All 28 hernias in this series were successfully repaired through a transthoracic approach, usually under endotracheal anesthesia. The excellent exposure so easily obtained by this approach made it preferable to the abdominal approach. In a number of instances, the herniated structures extended up to the dome of the thorax, and the adhesions present could have been handled only with great difficulty through an abdominal incision.

Closure was eventually accomplished in every case in the series, though in some, at first glance, it was doubtful that enough diaphragmatic tissue remained to be useful. After careful dissection, however, enough tissue was developed to permit satisfactory closure in every such case, though it was sometimes necessary to dissect the extension of the diaphragm into the transversalis muscle before closure could be accomplished without tension. Two rows of silk sutures were used, the second burying the first. When the diaphragm was detached from the thoracic wall, secure closure was achieved by using mattress sutures through the chest wall. The sutures were tied over tubes, and another row of interrupted intrapleural sutures was placed.

In the first cases in this series, the phrenic nerve was not crushed unless the line of the defect was such that contraction of the diaphragmatic fibers would exert a pull on the suture line. This technique was later made routine because, in a case in which it had been omitted, a hernia recurred 5 hours after operation, presumably because of excessive movements of the diaphragm during tracheal aspiration. Successful secondary repair was carried out several months later. There was no evidence that paralysis of the diaphragm retarded healing, and earlier experimental evidence by Meade (*2*) had shown that it did not decrease the tensile strength of the diaphragm.

Drainage was employed only three times, once when a gangrenous colon had to be resected and twice when empyema had preceded the hernia. Water-seal drainage was used in these three cases until the lung had fully reexpanded and obliterated the pleural space. There were varying degrees of pulmonary collapse in all cases in this series, but the lung reexpanded in all without difficulty, no matter how long the collapse had been present.

Postoperative management.—The usual routine of postoperative management was employed in these cases. Gastric suction was always instituted, usually for 72 hours. If the patient could not keep the airway clear by his own efforts, endotracheal aspiration was used.

Postoperative complications.—There were only three postoperative complications of any consequence. In one case, as already mentioned, there was an immediate recurrence of the hernia. In one case, in which the lung was damaged while it was being separated from the herniated liver, a temporary pneumothorax developed. In one case, there was a postoperative recurrence of the empyema which had complicated the original injury and which had to be treated before repair of the hernia could be undertaken. In three other cases transient pleural effusions appeared, but they disappeared promptly and did not delay recovery.

HERNIA OF THE LUNG

General Considerations

Hernia of the lung was an extremely infrequent complication of combat-incurred wounds, probably because of the inherent elasticity of pulmonary tissue. This property causes the tissue to contract and retract from the chest wall when intrapleural and intraplumonary pressures become equal in the presence of the opening into the pleural cavity caused by a chest wound. The concomitant pneumothorax and hemothorax that occur after wounding also act to prevent pulmonary hernias. On the other hand, in view of the considerable number of large chest wall defects observed in forward hospitals, the rarity of pulmonary herniations is remarkable.

According to Funk (*3*), who made a comprehensive review of the literature in 1918, only three hernias of the lung were reported in the Civil War, and none were recorded in the Crimean War or in World War I. In the South African War (1899–1900), Makins (*4*), in an extensive experience, observed only one case. Adams (*5*) found only 5 pulmonary hernias in 20,000 wounds of the chest in the Russo-Japanese War. Up to 1945, only 185 cases had been recorded, most of which were combat-incurred.

Occasional instances of hernias involving single pulmonary lobes were observed, but there was only one instance of true pulmonary hernia (fig. 65) in the 2,267 thoracic and thoracoabdominal wounds in the 2d Auxiliary Surgical Group experience. Of the seven cases recorded from the section of thoracic surgery, Walter Reed General Hospital, Washington, D.C., by Capt. (later Maj.) Elmer P. R. Maurer, MC, and Lt. Col. (later Col.) Brian Blades, MC, six were combat-incurred, and the other was the result of trauma.

Traumatic hernias represent the largest group of pulmonary hernias. They have been reported after crushing wounds, stab wounds, and perforating wounds caused by rifle bullets and shell fragments. They occasionally appear after surgical procedures. The congenital and spontaneous varieties are decidedly infrequent.

In traumatic hernias, the first manifestation is the appearance, usually from several weeks to several months after injury, of a tender swelling in the chest wall, which increases in size on forced expiration and disappears on inspiration. In acute traumatic hernias, the symptoms referable to the hernia are obscured by the symptoms arising from the injury itself.

The diagnosis is usually made without difficulty because of the characteristic behavior of the air-containing tissue. In four cases observed at Walter Reed General Hospital, however, the classical signs and symptoms of pulmonary hernia were present, but at operation no lung tissue was found in the defect in the chest wall. In three of these cases, the liver had herniated into the defect. The clostridial infections which occur in crushing injuries of the chest wall may produce crepitant bulging in soft tissues, but the circumstances make it unlikely that the infection will be confused with a true hernia of the lung.

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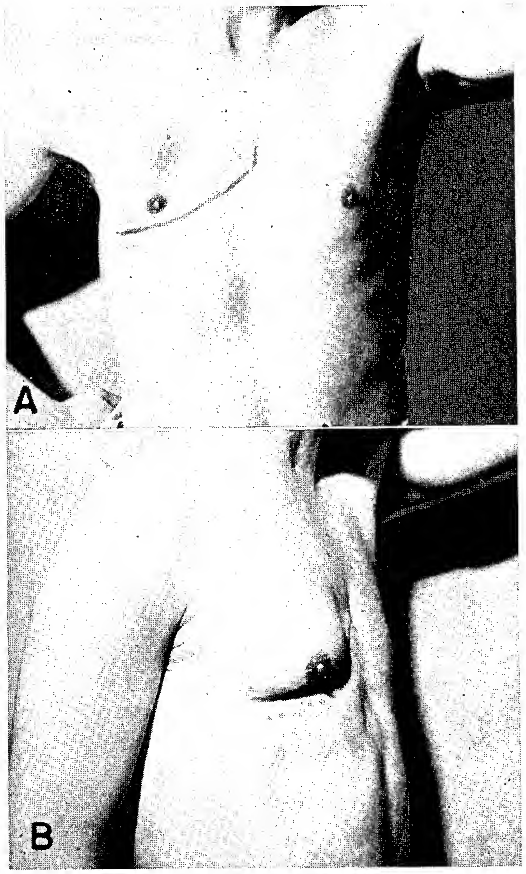

FIGURE 65.—True hernia of lung. A. Anterior view showing retraction of chest wall when patient holds breath. B. Anterolateral view showing bulging on forced expiration. This patient sustained a penetrating shell-fragment wound through the anterior chest wall, with loss, by injury and subsequent debridement, of the third and fourth costal cartilages and the anterior segments of the corresponding ribs. Three weeks after injury, protrusion and retraction of air-containing tissue were noted through the defect in the chest wall. The phenomenon was not attended with symptoms. When the patient was evacuated to the Zone of Interior, roentgenograms showed periosteal regeneration and it was thought that, with stabilization of the chest wall, the pulmonary hernia would undergo spontaneous cure.

Management

Because of the infrequency of hernias of the lung, it is not possible to make many definitive statements about their management. Emergency measures were not necessary, and there was no indication for operation overseas. The symptoms could be easily controlled by pressure dressings over the defect, and spontaneous healing was always a possibility.

Except for such complications as might be introduced by the wound, there was nothing in the management of pulmonary hernias of traumatic origin encountered in wartime that differed from the management of similar hernias in civilian practice. Operation was always performed under endotracheal anesthesia, to avoid risk when the pleura was opened widely, as well as to leave the lung in the desired state of inflation after operation.

At Walter Reed General Hospital, tantalum plates were employed tentatively, but the method had to be abandoned because of the impossibility of maintaining immobility of the plate on the constantly moving thorax. In the five true hernias in which operation was performed at this hospital, plastic repair was accomplished with structures of the chest wall only (rib, periosteum, and muscle.) The most important feature of the repair was coverage of the defect in the chest wall with sturdy bone or with periosteum that would produce bone. After appropriately located ribs had been divided and released from their periosteal envelopes, they could be shifted until the gap was bridged. They were then anchored in the desired position by pericostal fixation, by suture to the fascia or adjoining periosteum, or by fastening the mobilized rib to an adjacent rib with absorbable sutures threaded through drill holes.

An essential point of repair was the creation of a local pneumothorax, so to speak, by freeing of adhesions and of lung tissue about the margins of the hernia orifice. The pneumothorax thus produced acted as a cushion between the lung and the freshly repaired chest wall and reduced to a minimum the chances that the lung would be forced into the chest wall if the patient coughed or strained immediately after operation, when the repair was weakest.

Case History

Case 5.—This 25-year-old soldier sustained a penetrating shell-fragment wound of the right chest on 15 January 1945. Treatment consisted of closure of the wound by suture, intercostal water-seal drainage for 3 or 4 days, and three aspirations of the chest.

When he was admitted to Walter Reed General Hospital about 6 weeks later, his only complaint was mild pain in the right chest, not associated with hemoptysis or cough. A well-healed linear scar, 11 cm. long, was present in the right anterolateral chest. A second, well-healed scar, 9 cm. in length, was present along the vertebral border of the right scapula. Percussion and auscultation of the chest revealed no abnormalities. Roentgenologic examination revealed a metallic foreign body, 7 by 7 mm., and several smaller metallic foreign bodies, in the right lung. A defect in the right sixth rib laterally measured 8 centimeters. It was possible to insert three fingers into this defect for about 1 centimeter. When the patient coughed, as well as on forced expiration, with the glottis closed, there was a definite bulging through the defect.

Operation was performed on 8 June 1945, under endotracheal ether anesthesia, by the following technique (fig. 66):

An incision was made over the defect in the right anterolateral chest wall at the level of the sixth rib. The skin and muscles were divided. When the muscles were dissected free, the lung was exposed. It was found adherent to the chest wall. The adhesions were divided and the lung was separated from the chest wall over an area 10 cm. in diameter.

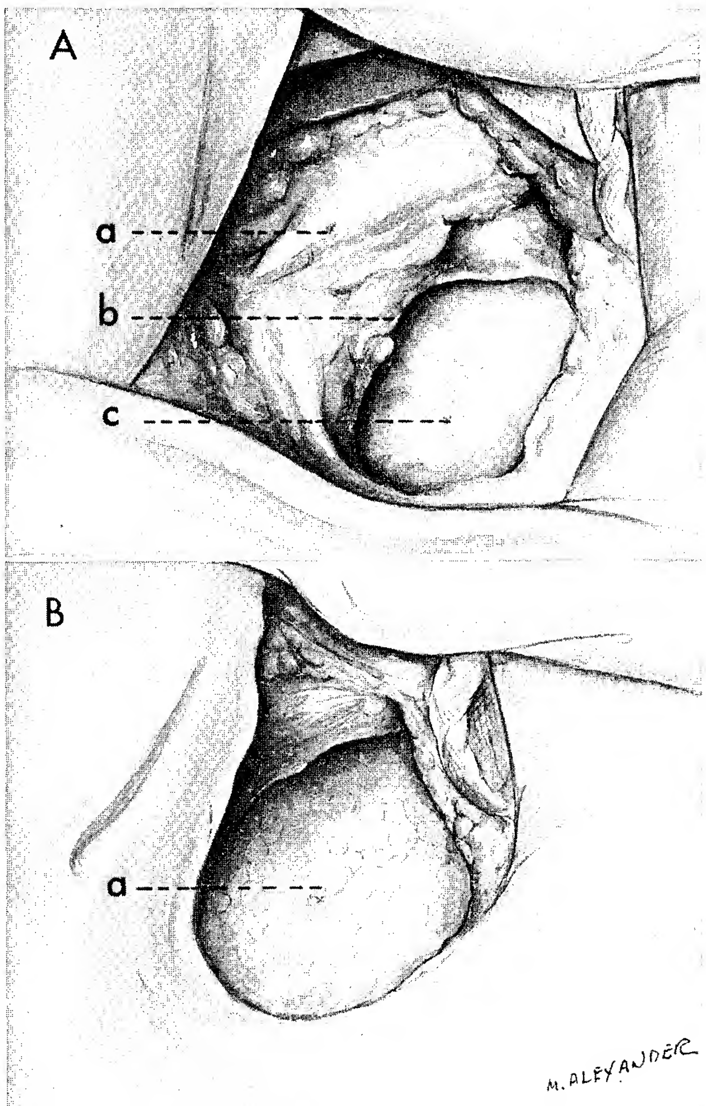

FIGURE 66.—Technique of repair of pulmonary hernia. A. Division of muscles of chest wall (a), disclosing margins of defect (b), adherent lung, and pleural sac (c). B. Release of lung (a) and pleural sac from margins of defect.

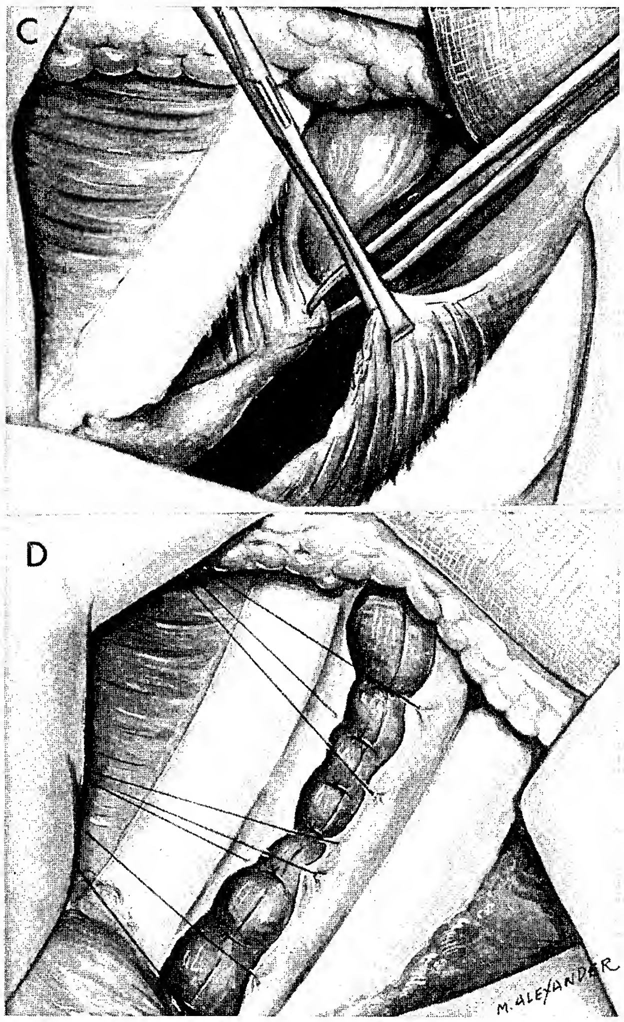

FIGURE 66.—Continued. C. Development of intercostal muscle bundles, to be used as first layer in closure of defect. D. Approximation of intercostal muscle bundles with medium silk sutures. Development of periosteal flaps from ribs above and below margins of defect.

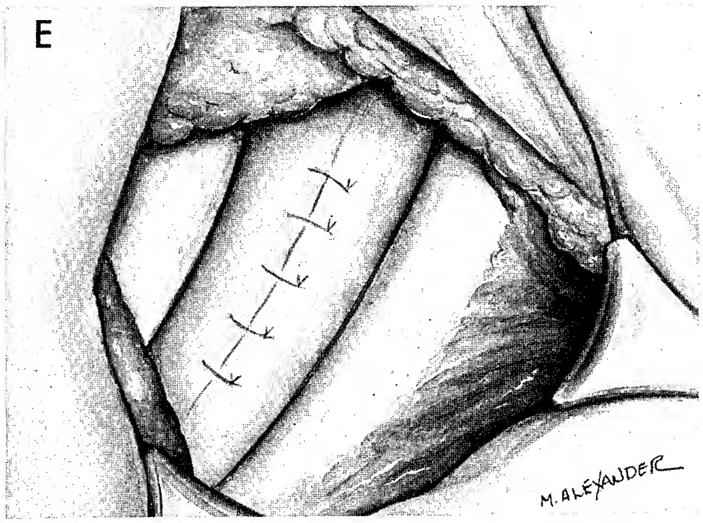

FIGURE 66.—Continued. E. Suture of periosteal flaps over intercostal muscles to form second layer of closure and complete repair.

The periosteum of the fifth and seventh ribs was developed into flaps, which were sutured in place to bridge the defect. The first layer of closure consisted of intercostal muscles brought together with interrupted sutures of medium silk. The ribs were then approximated with retractors, and the two flaps of periosteum were joined with interrupted sutures of medium silk. No effort was made to reinflate the lung, because, as just pointed out, it was desirable to maintain a residual localized pneumothorax for a time. The muscles of the chest wall were brought together with interrupted sutures of fine silk, and the skin was similarly closed, without drainage.

Convalescence was entirely uneventful. The wound healed per primam. The soldier was sent on a convalescent furlough 4 weeks after operation, and when he was reexamined on 14 August 1945, the area of the defect was firm, and there was no evidence of recurrence of the hernia.

RESIDUAL SYMPTOMS

General Considerations

A large number of patients who had sustained chest injuries presented a triad of residual symptoms, consisting of shortness of breath, soreness of the chest, and paresthesias or pains in the affected side. These symptoms were observed at various times after wounding, in both oversea and Zone of Interior hospitals. At the Walter Reed General Hospital, they constituted the most serious obstacle to returning men with chest injuries to full duty within a short period of time.

Dyspnea was usually mild, but it appeared on very little physical exertion, and most patients complained of reduced exercise tolerance. It was often necessary for them to fall out of ranks.

Pain was usually vague and usually paresthetic in nature. The patient distinguished it from soreness, which most of them complained of at night, when they tried to sleep on the affected side.

Except for variations in degree, the symptoms were consistent. They bore no discernible relation to the type of injury sustained. They were as frequent in simple penetrating wounds of the chest with no consequences beyond hemothorax as they were in more severe injuries. They occurred whether or not thoracotomy had been performed. They also occurred whether the soldiers were returned to combat duty or were given limited-duty assignments.

Special Studies

When this problem became of importance in thoracic surgery centers in the Zone of Interior in chest casualties who otherwise could have been returned to duty, it was found that very little was known about it. There were no subjective studies of dyspnea on exertion in such cases, and no objective studies by determinations of the vital capacity to investigate possible permanent damage.

At the Walter Reed General Hospital, a study of the intercostal pain and numbness which followed thoracic injury was undertaken by Maj. Donald L. Rose, MC. Three methods were used:

1. The patient was asked to outline the painful area on his chest wall.
2. A complete neurologic examination was made.
3. Skin resistance tests were carried out by the Richter technique, to check the impressions gained by other examinations.

With few exceptions, the patient's own zoning of pain points on his chest wall corresponded with the results of the skin resistance tests. In the few cases in which the results of the examinations did not coincide, it was thought safe to discount the symptoms.

These studies established three practical points:

1. There was no satisfactory treatment for damaged intercostal nerves once they had been injured. Intercostal nerve block provided temporary relief, but, once the immediate effects had disappeared, the pain was sometimes more severe than it had been originally.
2. Injury to a single intercostal nerve did not cause serious residuals.
3. If three consecutive nerves were crushed or cut, prolonged discomfort followed, and it was serious from the standpoint of future vigorous activity.

Major Rose's study showed that residuals from the bruising of a single nerve were of little consequence, whether it was damaged during rib resection or in the course of an intercostal incision. Injury of at least two nerves was necessary to produce symptoms. Pressure transmitted from the rib-spreading retractor was apparently of little consequence.

Management

This problem was of extreme importance in military medicine. In civilian practice, it would have been considerably less serious. A civilian with discomfort after a chest injury could generally avoid activity which might aggravate it. The situation was quite different in military service, in which the soldier who was ordered to drill, carry a pack, or perform some other activity had no recourse but to obey orders as long as he was on active duty.

In military practice, furthermore, the medical officer was obliged to make a decision as to the validity of the patient's complaint. He had to consider seriously whether the pain was genuine and severe, or whether the soldier was motivated by a desire to escape active duty or to be separated from service. If the surgeon discounted the symptoms and sent the soldier off to duty when he was really unfit for it, he might do him a serious injustice.

Since the etiologic factors in postwounding discomfort were not clarified during the war, treatment was unsatisfactory. The variable results in nerve block have already been mentioned. Psychotherapy was useful in some cases.

As a result of the study conducted at Walter Reed General Hospital, it was concluded that the solution of the problem was preventive, to exercise extreme care in handling intercostal nerves at operation and to avoid, as far as possible, any surgical technique that might traumatize them unnecessarily. The corollary of this reasoning was that pericostal and perichondral sutures should not be used. Encircling sutures of this kind had been used in a number of the patients observed, with resultant temporary destruction of two or more nerves.

Surgeons at Walter Reed General Hospital believed that it was seldom necessary to employ pericostal and perichondral sutures to accomplish a satisfactory closure of the chest wall. If the wound was posterior, particularly if a segment of rib had been resected, it was not necessary to hold the ribs together by sutures. Even when an intercostal incision was employed, there was usually sufficient tissue to close the defect without fixing the exposed portion of the thoracic cage with encircling ties.

The following technique was found satisfactory for the closure of practically all surgical wounds of the chest:

> Interrupted sutures were placed in the intercostal muscles while the ribs or cartilages were brought together with retractors. The placing of the instruments was important: The lower retractor must be placed not in the interspace adjacent to the wound but at least one interspace lower. The pressure from this retractor would be transmitted directly against the nerve on the inferior edge of the rib if it were placed in the adjacent interspace. By placing it one or two interspaces lower, injury to two or three consecutive intercostal nerves, which this study had shown to be responsible for painful sequelae, could be avoided.[3]

[3] The reader is referred to chapter XI (p. 441) for long-term followup studies on casualties with a number of the complications of thoracic wounds described in this chapter.

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CHAPTER V

Wet Lung

Thomas H. Burford, M.D.

CONCEPT AND GENERAL CONSIDERATIONS

During the first year of fighting in the North African Theater of Operations, U.S. Army, it gradually became apparent that casualties with fluid in the lungs, in contrast to those whose lungs were dry, presented many difficulties of management. They required strenuous efforts at resuscitation if they were in shock, and they did not respond well to them. They presented poor surgical risks when emergency surgery was necessary. They were prone to develop postoperative pulmonary complications, especially if they had coughed up large amounts of blood before operation. Fatalities were proportionately more frequent among them than among casualties with similar wounds whose lungs did not contain fluid. When these patients came to autopsy in forward hospitals, pulmonary edema was the most prominent finding.

Although most surgeons in the theater were aware of the phenomena just described, the extreme seriousness of the problem was not immediately realized. There was nothing in the civilian experience to call attention to pulmonary edema as an immediate consequence of thoracic injuries.[1] As a result, more than a year was to pass after the onset of fighting in North Africa before the concept of what came to be known as wet lung was developed and appropriate methods of treatment were devised.

The term "wet lung" and the concept which underlay it were first presented by Maj. Thomas H. Burford, MC, and Maj. Benjamin Burbank, MC, at a meeting of Fifth U.S. Army surgeons at the 38th Evacuation Hospital at Riardo in February 1944. At the same time, they discussed its etiology and outlined the principles of prevention and correction.

In their first presentation on this condition, Major Burford and Major Burbank described wet lung as a more or less specific response of the lung and chest wall to trauma. They postulated the operation of a somatovisceral reflex originating in the chest wall and mediating alveolar and bronchiolar

[1] In 1937, Betts and Overholt (*1*) described a syndrome which sometimes occurred from 24 to 48 hours after thoracic surgery, usually at night, and which consisted of slight cyanosis, noisy respirations, depression of the cough reflex, and a shocklike state. No matter how hard the patient tried, he could not raise the secretions whose retention was producing anoxia and anoxemia. The only way to break the cycle was to remove the retained secretions, for which bronchoscopic aspiration was necessary. In a number of respects, this syndrome seems to resemble the wet lung encountered in combat-incurred injuries.

responses. They particularly emphasized the part played by the painful chest wall in the pathogenesis of wet lung. It was the chief explanation of the patient's inability to raise the secretions formed in excess as the result of trauma. The immobilization of the chest wall made effectual coughing impossible, and the result was the saturation of the tracheobronchial tree with secretions which, under normal circumstances, would have been coughed up.

Major Burford and Major Burbank further suggested that a definite one-two relation probably existed between the wet lung of trauma and the massive pulmonary collapse which was so common in World War I. Their theory was that the wet phase, which was not recognized, precipitated the second phase, in which massive collapse occurred (p. 210).

The concept of wet lung, as presented by Major Burford and Major Burbank, was precise and specific. Later, Maj. Lyman A. Brewer III, MC, and other chest surgeons in the Mediterranean Theater of Operations, U.S. Army, expanded the original concept into a looser, broader concept of traumatic wet lung. In this later concept, the term "wet lung" was used for all forms of retained tracheobronchial fluid resulting directly or indirectly from trauma.

Recognition of the importance of wet lung in no wise detracted from the importance of the primary lesion or of associated injuries. On the contrary, it permitted a more rational approach to the entire problem of combat-incurred chest injuries. The important considerations stressed by Major Burford and Major Burbank were as follows:

1. The chest reacts to trauma in a way peculiar to itself, whether the injury is a slight contusion of the chest wall or a severe penetrating or perforating injury.

2. The reaction caused by trauma profoundly influences the whole pathologic process, the therapy applied, and the prognosis.

PATHOGENESIS AND PATHOPHYSIOLOGY

The pathogenesis of wet lung can be understood only if the normal physiology of the respiratory tract is borne in mind. In addition to its function as an airway, the tracheobronchial tree has a definite secretory function, combined with the capacity to rid itself of its own secretions and of aspirated material or other fluid substances which do not normally belong within its lumen. Evacuation of the tracheobronchial tree is accomplished (1) involuntarily, by action of the cilia and movement of the bronchial musculature, and (2) voluntarily, by coughing.

In spite of the extensive experience of World War II, little is yet understood concerning the effect of trauma to the chest on the function of the bronchial cilia and on other factors influencing the passage of secretions through the tracheobronchial tree. The presumption seemed warranted that after trauma, these functions became depressed or were perhaps entirely interrupted. Clinically, it was clear that the normal cough mechanism was

seriously impaired in the presence of moderate and severe trauma, and sometimes of slight trauma.

The lung, which is a specialized organ, reacts to trauma in just as specialized a manner as does the brain or any other specialized organ. In combat casualties with chest injuries, the pulmonary reaction took two forms:

1. The production of an excess of secretions or, in the broader concept of Major Brewer and his associates, of transudates and extravasated blood also.
2. The development of conditions which prevented the normal and adequate elimination of these fluids.

At present, there is insufficient evidence to permit formulation of a precise explanation for this dual process. Experimentally, de Takats and his associates (*2*) demonstrated that any appreciable trauma to the chest wall was followed almost immediately, in 60 percent of the animals, by widespread bronchial spasm and increased bronchial secretions. Bronchial spasm of the same degree could also be produced by stimuli applied within the abdomen, such as traction on the cystic duct or the mesentery.

It would be tempting to apply these experimental results to combat casualties and to postulate the existence of reflex bronchial and bronchiolar spasm originating after trauma as the result of a painful chest wall or pleura, but there are two reasons why the transfer would not be justified:

1. The whole case for bronchospasm rests on evidence that is still far from acceptable.
2. The hypothesis of bronchial spasm would explain only part of the phenomena observed in traumatic wet lung.

Even though it was not possible to explain the initial effect of thoracic trauma on the function of the tracheobronchial tree, the course of events afterward was quite clear:

1. The presence in the tracheobronchial tree of mucoid secretions in far more than normal amounts, as well as of transudates, blood, and aspirated material caused a mechanical obstruction and prevented adequate oxygenation of the alveoli.
2. With the suppression of the normal cough reflex, the tracheobronchial tree became increasingly less capable of eliminating secretions, and more fluid accumulated in it.
3. As these conditions continued, less oxygen became available to the pulmonary capillaries. It could be assumed from the work of Drinker and Warren (*3*) that anoxia increased capillary permeability and permitted more plasma to be lost into the tissues. Increased amounts of fluid extravasated from the pulmonary capillaries into the alveoli further decreased the oxygen available for the bloodstream.
4. The plugging of branch bronchi with secretions prevented the exchange of gases in the lobules supplied by these bronchial divisions, and lobular atelectasis resulted.

5. Plugging of a branch bronchus to a lobe or of a stem bronchus to a lung increased the anoxic anoxia that was the result of partial obstruction, for two reasons: (1) The alveolar bed available for the absorption of oxygen was far smaller than normal, and (2) sooner or later, a mediastinal shift resulted.

When blood was present in the tracheobronchial tree as the result of trauma, it could, in itself, cause bronchial obstruction. It also had another effect, that the irritation of the bronchial mucosa that it caused was responsible, in turn, for an increase of tracheobronchial secretions.

When wet lung appeared soon after wounding, its most potent effect was the promotion of anoxia. When it persisted or was allowed to progress without treatment to the point just described, it paved the way for subsequent pulmonary complications. A patient who was not too severely wounded and in whom other conditions were favorable might recover from his initial shock without complete removal of the fluid that was producing obstruction of the tracheobronchial tree. In such an instance, however, the causative factors were unchanged, and the stage was set for the development of tracheobronchitis, atelectasis, pneumonitis, and pneumonia. Wet lung sometimes seemed to be the chief factor upon which the outcome of an injury hinged. Failure to take active measures to combat it could lead to chronic pulmonary invalidism, and, before this complication was clearly understood, more than one patient with an uncontrolled wet lung died from this cause alone.

It was of the greatest importance that anoxia be relieved promptly. If it was not, serious changes occurred in other organs, particularly in the central nervous system, which is highly sensitive to an oxygen deficit. Severe cerebral anoxia, even if it persisted for only a short time, could result in serious cortical impairment. The psychotic manifestations and coma observed in some patients with chest injuries could reasonably be attributed to this cause.

There was clear clinical evidence of the relation of the pathophysiologic disturbances produced by wet lung to the patient's general status. In numerous instances, shock which had not responded to standard replacement therapy and other resuscitative measures, or which had become deeper as they were in progress, cleared up quickly, and even dramatically, when appropriate measures for the relief of wet lung were instituted.

As clinical experience accumulated, the theory seemed reasonable that a definite relation might exist between the wet lung of trauma as it was recognized in World War II and the massive pulmonary collapse described by Pasteur (*4*) in 1914 and described later, under the name of acute massive atelectasis, by Churchill (*5*). It was an attractive hypothesis to conceive of wet lung as the antecedent stage, and in a sense the precipitating cause, of silent massive pulmonary collapse.

Such an assumption would explain the extreme rarity of massive pulmonary collapse in the Mediterranean theater, where surgeons became increasingly alert to the recognition of wet lung and increasingly vigorous in its

treatment. Minor degrees of atelectasis were frequently observed in cases of wet lung which were inadequately treated.

ETIOLOGIC FACTORS

The events just described were most often observed after chest injuries. Wet lung, however, was a possibility in other injuries, including thoracoabdominal injuries, abdominal injuries, and head injuries, particularly those that were associated with coma and unconsciousness.

Usually, though by no means always, the degree of wetness depended upon the type and severity of the primary lesion, the size and velocity of the missile, and whether or not the missile had struck a portion of the bony cage or only the soft tissues. The size of the intrapulmonary vessels that were damaged had a bearing on the amount of blood extravasated. Wet lung was present to some degree in practically all cases of thoracic trauma, though it might be transitory or so slight as to be almost unrecognizable clinically even when it was carefully searched for. Sometimes, too, the primary thoracic lesion was of such severity that it masked the underlying physiopathologic substratum. In many cases, on the other hand, wet lung was present to a far more severe degree than might have been expected from the relative mildness of the initial wounds.

A number of other factors played a part in the causation of wet lung:

Pain

Pain was an almost invariable component of chest trauma. Its exact influence in the production of wet lung was never fully clarified, but there was no doubt that it played an important part in both its inception and its progress. It had at least three harmful effects:

1. It induced a shallow type of respiration, for protective reasons.
2. The natural reaction to pain was voluntary splinting of the affected area.
3. The affected hemithorax therefore moved less than the unaffected side, with a resultant decrease in the movement of air back and forth in the bronchi. A decrease in the tidal respiration was probably of more importance than was at first recognized, as it lessened the amount of secretion that might be disposed of by evaporation.

Suppression of the Cough Reflex

The normal voluntary cough mechanism consists of four steps:

1. The air is drawn voluntarily into the lungs by raising the ribs and lowering the diaphragm.
2. The breath is held momentarily by closing the glottis.

3. The abdominal muscles are tensed, the intercostal spaces are narrowed, and the diaphragm is relaxed to provide explosive force.

4. The glottis is then suddenly opened, and the bechic blast required to raise the sputum is thus released.

A number of conditions present in chest trauma prevented the succession of steps just listed, all of which are necessary for effective coughing. Pain arising in either the chest wall or the pleura prevented both expansion and forceful contraction of the thorax. Rib fractures were frequently associated with severe pain when either coughing or deep breathing was attempted. If there were multiple fractures of the ribs or of the sternum, with a resulting flail chest, the paradoxical movement of the chest wall made effective coughing impossible. On inspiration, it moved outward. Attempts at coughing simply aggravated these paradoxical movements.

Wounds that caused abdominal pain, whether they were located in the abdomen or in the chest, prevented the tensing of the abdominal muscles necessary for an effective cough. The pistonlike action of the diaphragm, which is a part of the act of coughing, was impossible in a diaphragmatic injury. Ileus, acute dilatation of the stomach, and the presence of free fluid in the peritoneal cavity also had a more or less inhibitory action on the cough mechanism.

Sedation and Anesthesia

Oversedation from the too-liberal use of morphine was a fairly frequent contributing cause of wet lung. As their experience increased, shock officers in field and evacuation hospitals learned to be constantly on their guard against giving morphine to freshly wounded casualties. Often the patients did not need it at all. They were simply apprehensive as the result of anoxia and disturbed and uncomfortable from the ambulance ride. When morphine was really needed, it was given intravenously, not subcutaneously, in ¼-gr. or at most ½-gr. doses.

Early in the war, as pointed out elsewhere (vol. I), and much less often later in the war, casualties with fractured ribs, flail chests, and other painful thoracic and abdominal wounds often arrived in the shock wards of field and evacuation hospitals with overdosages of morphine compounding their original difficulties. For a variety of reasons they had received too much medication. Respiratory distress was sometimes as inherently frightening to the inexperienced medical officer as to the casualty, and efforts made by these officers to relieve the patient were sometimes as frantic and ineffectual as the patient's own efforts to get his breath.

Whatever the background, oversedation invariably led to an increase in the accumulation of secretions in the tracheobronchial tree and a decrease in the cough reflex. As a result, shock was increased, and preparation of the casualty for emergency surgery or for further evacuation became more difficult.

Prolonged administration of an inhalation anesthetic to a patient in poor condition, whose reaction was delayed after operation, often led to the retention of bronchial secretions and to later pulmonary complications. This was particularly true if the airway had not been kept clear by catheter suction during the operation and if bronchoscopy had not been performed at the conclusion of the procedure when there was any doubt at all about the efficacy of suction.

Preexistent Respiratory Infection

It was not unusual for secretions to be present in the bronchial tree before injury. Soldiers who had undergone exposure during combat, particularly during the cold, wet months of winter, frequently had upper respiratory infections or frank bronchitis, associated with mucopurulent secretions. In the Mediterranean theater, preexistent respiratory infections were often aggravated by the circumstances of evacuation. During the mountain fighting in the winter of 1943–44, casualties had to be brought down the mountain by litter carry. Often as many as 8 to 12 relays were required between the battalion aid station and the collecting station. As a result, exposures of 12 hours or more after wounding were not unusual.

Overhydration

No matter how urgently replacement therapy might be needed, it had to be instituted judiciously in patients whose cardiorespiratory physiology was disturbed after wounding (vol. I). The administration of too much plasma in battalion aid and clearing stations, or even of too much blood in field and evacuation hospitals, might place such an extra load on the circulatory system that pulmonary edema might develop and contribute to the etiology of wet lung arising directly from the wound.

CLINICAL PICTURE

Wet lung usually appeared shortly after wounding, sometimes within a few hours. Less often, it did not develop for as long as 5 or 6 days after injury.

The presence of abnormal amounts of fluid in the tracheobronchial tree in thoracic injuries was manifested by certain cardinal symptoms and signs, the early recognition of which prevented the development of graver complications. Cough and dyspnea were the chief symptoms, and rales were the predominant physical finding.

Symptoms.—The cough associated with wet lung was usually described as a wet cough because of the rattling or gurgling element always present in it. It might be hacking, harassing, continuous, or paroxysmal. Small amounts of sputum were often raised by constant coughing, but the cough remained moist; because there was little expulsive force behind it, it was never fully productive.

Inexperienced medical officers might receive the impression that, because some sputum was raised, tracheobronchial drainage was good, but the persistence of wheezes and rattles in the chest proved that it was still poor. As a matter of fact, only the most superficial secretions were raised, just as small amounts of fluid are splashed out from the top of a full cup that is continuously replenished.

The dyspnea characteristic of wet lung could be explained in a number of ways. It might be the result of painful, jerky, shallow respirations, each inspiratory effort being limited by the pain that the preceding effort had caused. When trauma had been considerable, the explanation might be hemothorax or mediastinal shift. When damage had been minimal, the most reasonable explanation was partial bronchial obstruction with resulting anoxia. Some patients seemed to be having typical asthma. Apprehension was an occasional cause of dyspnea.

When dyspnea was extreme, orthopnea, restlessness, excitement, and disorientation were present as the result of cerebral anoxia.

Signs.—The patient's appearance varied according to the severity of his injury and whether or not he was in shock. Fever and evidences of toxicity were constantly present in late cases.

Respirations were frequently grunting because they were painful. Motion was usually restricted over the involved area of the chest. Breath sounds were reduced in intensity, but if hemothorax, pulmonary hematoma, or some similar complication were not associated with the injury, the percussion note and the tactile fremitus were unlikely to be materially altered.

The most characteristic physical finding in wet lung was the presence of rales, bronchial in character. They were sometimes heard on both sides of the chest; their bilateral presence was a valuable diagnostic sign. More often, they were more intense on the injured side. They ranged from high-pitched wheezes, which some surgeons considered indicative of associated bronchospasm, to medium or coarse bubbling rales or rhonchi. Rales that were wheezing and high-pitched sometimes had a dry quality. Sometimes fine rales that were predominantly moist or bubbling were so numerous as to suggest the type heard in simple, nontraumatic pulmonary edema or in bronchial asthma. These rales were frequently bilateral. Bubbling, sonorous rales were sometimes heard in combination with a classical tracheal rattle; in such cases, the sputum was predominantly liquid.

Rales were often so loud that the stethoscope was not needed to identify them. They could be heard at the bedside, or even at some distance from the patient, just as in typical bronchial ashma. While all varieties and gradations of rales might be present in any single chest, diffuse moist rales were especially characteristic of the primary phase of traumatic wet lung.

Rales were sometimes not demonstrable unless the examination was made immediately after the patient had coughed. They might not be heard at all if sticky mucus was attached to the tracheal or bronchial wall or if a branch

bronchus was completely blocked. In such cases, fine crackling sounds could usually be heard if the stethoscope was placed over the patient's mouth.

As already indicated, a coexistent hemothorax, pneumothorax, or some other finding might so alter or mask the typical clinical symptoms and signs of wet lung that its existence would not be suspected unless the medical officer bore the possibility in mind.

DIAGNOSIS

Clinical observations.—In early stages of traumatic wet lung, the evidence of moisture obtained by auscultation was the most important diagnostic sign. The presence of rales anywhere in the chest, even over portions not involved in the trauma, was a valuable clue, indicating as it did that wet lung was either present or in process of development.

In advanced cases, the diagnosis, as already stated, could sometimes be made without the use of the stethoscope because dyspnea was so obvious and rales were audible even at a distance from the bed. The physical findings in late cases were those ordinarily observed in atelectasis and pneumonia. Distant bronchial breathing was often heard over small areas of the chest and might represent either patchy lobular atelectasis or a pneumonic process. The diagnosis of wet lung was established if the intensity or location of bronchial breathing changed with forced coughing.

The character of the secretions raised was also of diagnostic significance. Hemoptysis usually denoted pulmonary injury; the blood was fresh-looking when hemorrhage was recent and was clotted and mixed with mucus when it was not. If the secretions were the result of reflex stimuli from trauma to the chest or irritation from aspirated material, or were part of a very early infection, they were likely to be mucoid. As infection developed in the bronchial tree, they became increasingly purulent. The presence of purulent sputum could sometimes be explained on the basis of a preexisting respiratory infection and sometimes by the development of a new infection in the stagnated bronchial secretions. Thin, yellow, pink or colorless fluid, often frothy because of the admixture of air, indicated the pulmonary transudation and exudation (edema) typical of more advanced wet lung. Then, serosanguineous fluid suggested hemothorax with bronchopleural fistula. Similarly, thin, seropurulent fluid suggested early empyema with bronchopleural fistula. Most often, the sputum represented a combination of the types described rather than a single, clear-cut type.

Roentgenologic examination.—While roentgenologic examination was highly desirable in all instances of chest trauma, it was always deferred until the patient was brought out of shock and steps had been taken to dry out the tracheobronchial tree.

The roentgenograms, which were taken, whenever possible, in at least two planes, were frequently difficult to interpret and were not always useful. In the initial stages of wet lung, roentgenologic changes were minimal, even when

there was clinical and auscultatory evidence of a considerable degree of obstruction and moisture. Patchy lobular atelectasis in the early stages might be indistinguishable from the shadows cast by a pulmonary hematoma (p. 165) or the pathologic process present in pulmonary contusion (p. 4). When intrapulmonary bleeding had occurred, the shadows were likely to be round or oval. When a hematoma was present, there might be evidence of small, loculated air pockets. Later, when lobular or total pulmonary atelectasis had occurred, the collapse of the affected parts of the lung produced the classical signs of mediastinal shift and narrowing of the intercostal spaces.

On the whole, while roentgenologic examination was sometimes useful and was never omitted because of the chest injury, the diagnosis of wet lung in the early stages was a clinical matter.

Differential diagnosis.—As a practical consideration, the question of differential diagnosis seldom arose in connection with traumatic wet lung. Theoretically, the condition had to be distinguished from bronchial asthma, pulmonary edema of cardiac origin, and pulmonary edema associated with peripheral vascular failure.

The differentiation was not difficult. The history of trauma and the absence of any history of previous asthmatic attacks promptly ruled out bronchial asthma. Since the young soldier was almost never a cardiac subject, the necessity of differentiating traumatic wet lung from pulmonary edema of cardiac origin almost never arose. Occasionally, however, patients with thoracic injuries had had such vigorous intravenous fluid therapy that the blood volume had become too much for an already embarrassed respiratory mechanism and right heart failure had supervened. In such cases, the manifestations of wet lung were interwoven with, and intensified by, those of right heart failure.

Pulmonary edema associated with peripheral vascular failure either from shock due to severe trauma or from an overwhelming toxemia was sometimes difficult to differentiate from wet lung, particularly when shock was associated with the latter. The nature of the exciting lesion, the pallor, low blood pressure, tachycardia, and weak, thready pulse had to be evaluated, as well as the response to attempts to clear the tracheobronchial tree. In wet lung, the response was usually rapid. If the pulmonary edema was associated with peripheral vascular failure, it would not respond to the therapy indicated for wet lung because its etiology was different.

PROPHYLAXIS

As their experience accumulated, medical officers came to realize that it was the part of wisdom to regard as a potential candidate for wet lung every casualty with a chest wound, a thoracoabdominal wound, a severe abdominal injury, or a head injury. On their admission to forward hospitals, all patients in these categories, particularly those who complained of thoracic pain or who presented dyspnea, wheezing, hemoptysis, and a cough, were carefully examined

for evidences of fluid in the pulmonary tree. The following routine was carried out:

1. Unless the patient was in shock or unconscious, he was placed in Fowler's position, so that the abdominal contents would gravitate into the pelvis. The diaphragm could thus act more effectively, with corresponding improvement in respiration and in the efficacy of the cough. The position was changed frequently if the patient could not turn himself. This measure was not always stressed as it should have been.

2. If the patient was dyspneic or cyanotic, oxygen was administered by nasal catheter or by the Boothby-Lovelace-Bulbulian mask.

3. If his breathing was at all wet, the patient was encouraged to cough (fig. 67A), the chest being supported manually whenever personnel could be spared for this purpose. The physical support of a painful chest was helpful, and the psychic effect was excellent; the patient was impressed with the importance of coughing because someone took the time and trouble to help him to do so. If he was sufficiently alert to comprehend, as already mentioned, the importance and rationale of coughing were explained to him, which made him much more willing thereafter to cough, in spite of any associated discomfort.

4. If the patient was conscious, complained of pain, and had evidently had no previous sedation, a small dose of morphine sulfate, preferably not more than gr. ⅛, was given by vein, so that it would act promptly and its effect on the painful chest could be more accurately evaluated.

5. The usual measures employed in all chest wounds were carried out. If the dressing covering a sucking wound was not already airtight, it was rearranged. The indicated resuscitative measures were instituted, with great care not to overload the circulation with fluids. The gastric tube was inserted if there was evidence of ileus or gastric distention (fig. 67B). If a hemothorax or tension pneumothorax was present, aspiration was employed to increase the vital capacity.

If wet lung had not yet become established but was merely impending or incipient, these measures were usually effective and the patient rapidly became a fit candidate for surgery in a forward hospital or could be safely evacuated to a fixed hospital.

MANAGEMENT

Principles

As already pointed out, the various factors responsible for wet lung constituted a vicious circle. They included accumulation of secretions in the smaller bronchi; limitation of normal respiratory motion because of pain; the suppression of the cough reflex, as well as of the desire to cough, because of pain; and the resultant effect of the wet lung on the oxygenation of the blood.

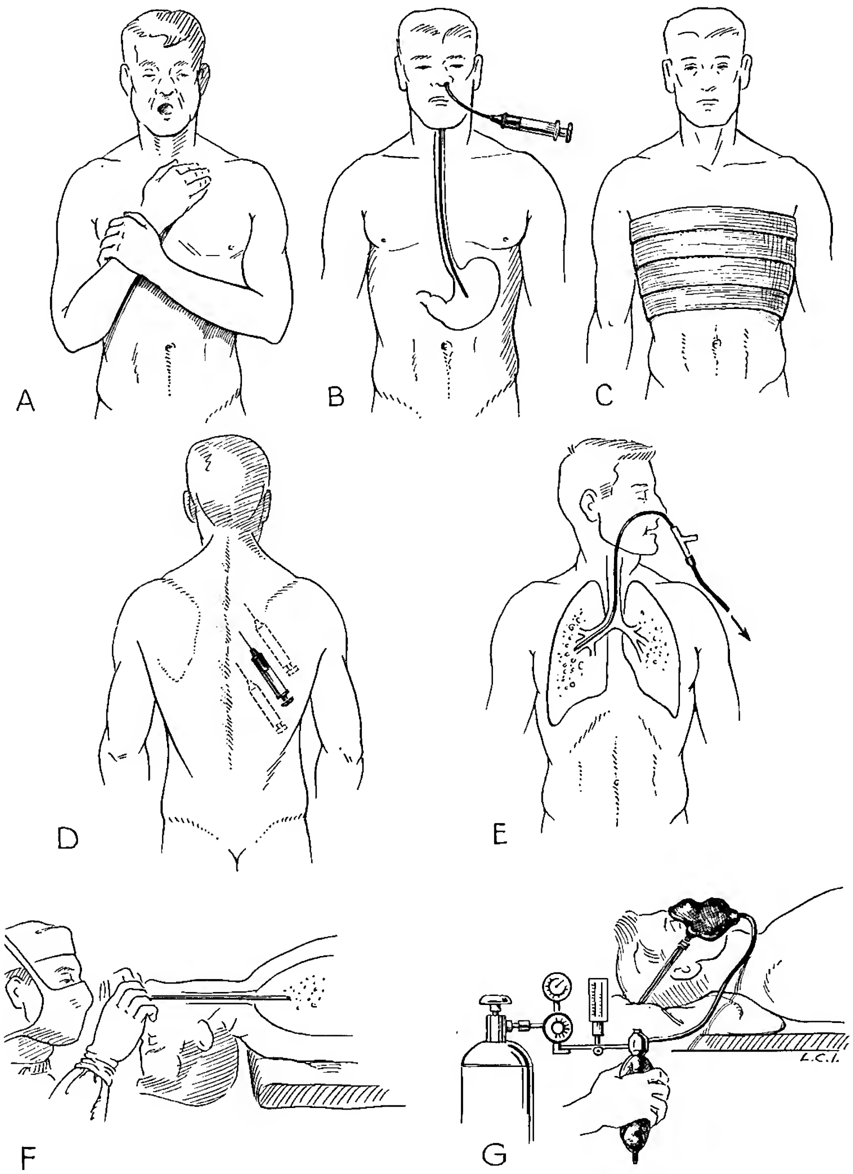


FIGURE 67.—Management of patient with wet lung. A. Clearance of chest by coughing, with patient supporting his own chest. B. Insertion of Levin tube for control of gastric dilatation. C. Application of elastic binder for stabilization of flail chest or external fixation of fractures. D. Intercostal nerve block (for details of technique, see fig. 68). E. Aspiration of bronchi by catheter passed transnasally. F. Bronchoscopy, which is resorted to if catheter aspiration is not successful. G. Administration of intermittent positive pressure oxygen therapy by manual compression of ventilatory bag of field hospital portable anesthetic machine.

Breaking this vicious circle by attacking its various components was the basis of the active therapy of established wet lung. In its active management, as well as in its prophylaxis, the principal aims of therapy were:

1. The maintenance of an open airway, so that inspired oxygen could reach the alveolar capillaries.
2. The prompt correction of conditions that were contributing to dyspnea, anoxia, and shock.

To achieve these aims, it was necessary to control the production of fluid in the lungs and to promote adequate bronchial drainage, as well as to institute such other measures as were necessary to correct the disturbed cardiorespiratory physiology.

Relief of Pain

Relief of pain and physiologic remobilization of the chest wall after thoracic injury were the sine qua non of a successful therapeutic effort in wet lung. In prewar civilian practice, the desired results had been achieved by adhesive strapping and the administration of morphine. These measures had never been physiologically sound. In combat-incurred injuries, both were ineffective, and even in stove-in chest, they were not necessary.

In severe flail chest with extreme paradoxical respiration, strapping of the chest or the use of a firm binder was occasionally necessary to prevent ballooning out of the chest wall (fig. 67C). The method was never officially forbidden, but with these very occasional exceptions, its use was avoided.

The administration of morphine was equally undesirable. It made the patient less aware of his discomfort, it is true, but it did not make the cough mechanism painless, and it diminished the cough reflex. Furthermore, by dulling the sensorium, it made the patient less aware of his own responsibility for overcoming his respiratory difficulties.

Intercostal Nerve Block

The most effective method of relieving chest pain and making it possible for a casualty with a chest wound to evacuate the tracheobronchial tree by coughing was intercostal nerve block at the site of injury (fig. 67D), or, alternatively, paravertebral sympathetic nerve block. One reason that it was necessary to employ both the intercostal and the paravertebral techniques of nerve block was that certain wounds were so situated that simple intercostal block was not always feasible.

Whether intercostal nerve block did more than abolish pain and effect an interruption of the reflex arc was a matter of speculation. It was, however, a logical procedure. According to Lewis (*6*), afferent pain impulses from the thoracic abdominal wall are transmitted by way of the sympathetic nerves, whose fibers accompany the intercostal nerves as far as the intervertebral foramina, whence they depart as rami communicantes to form part of the paravertebral sympathetic chain. There seemed little difference, therefore, between

interrupting the pain pathway by blocking the intercostal nerves or blocking the paravertebral chain through which pain impulses pass.

The nerves could be anesthetized at any point posterior to the lesion. At least three nerves were always injected, to provide a generous margin of anesthesia around the traumatized area. As many as 10 intercostal nerves or paravertebral ganglia could be blocked with safety, but when more than 4 or 5 nerves were to be injected, it was the policy to give a small preliminary dose of some barbiturate, to lessen the risk of a procaine hydrochloride reaction.

Local infiltration, which produced its effects by blocking the sensory end organs, was effective in simple, uncomplicated rib fractures with contusion of the chest wall, but it was contraindicated in casualties with open wounds, because all such wounds were potentially if not actually contaminated. Furthermore, the involved area in casualties with open wounds was frequently too extensive for local infiltration to be practical. This was sometimes, however, a valuable supplement to an extensive blocking procedure after which a small localized area of pain occasionally persisted, though an otherwise effective block had been obtained.

If the site of injury were so located posteriorly that even paravertebral block would require injection through contaminated tissue, paravertebral block incorporating at least two nerve segments above the superior margin of the injury was useful, for it blocked an appreciable number of the pain impulses which travel cephalad in the paravertebral sympathetic chain.

Technique of nerve block.—The needles used for intercostal nerve block were ordinary intravenous needles, 1½ inches long. A 1-percent solution of procaine hydrochloride was usually used, though an occasional surgeon preferred a 2-percent solution. An intradermal wheal was raised over the chosen rib at its angle over the inferior border of the rib between the costal angle and the wound or fracture site (fig. 68). Then the needle, without the syringe attached, was introduced through the wheal until the point had impinged lightly upon the inferior margin of the rib. From this point, with the bevel directed inferiorly, the needle was moved until the tip just cleared the inferior edge of the same rib. After the needle had been advanced about 0.5 cm., aspiration was carried out in two planes, to exclude the possibility that it might have entered a blood vessel. When this point had been settled, from 4 to 6 cc. of 1-percent procaine hydrochloride solution was introduced into the tissues. The total number of thoracic segments injected was determined by the number of ribs fractured or, if the lesion was a simple contusion, by the area involved.

Needles 3 or 3½ inches long were preferred for paravertebral nerve block. A small piece of loose rubber on the shaft indicated the depth to which the needle was to be inserted.

Paravertebral injection of the thoracic sympathetic ganglia was best performed with the patient in the lateral recumbent or the prone position. The sites for injection were marked on the skin, opposite the spinous processes and about 4 cm. lateral to the midline on the affected side. These points lie directly

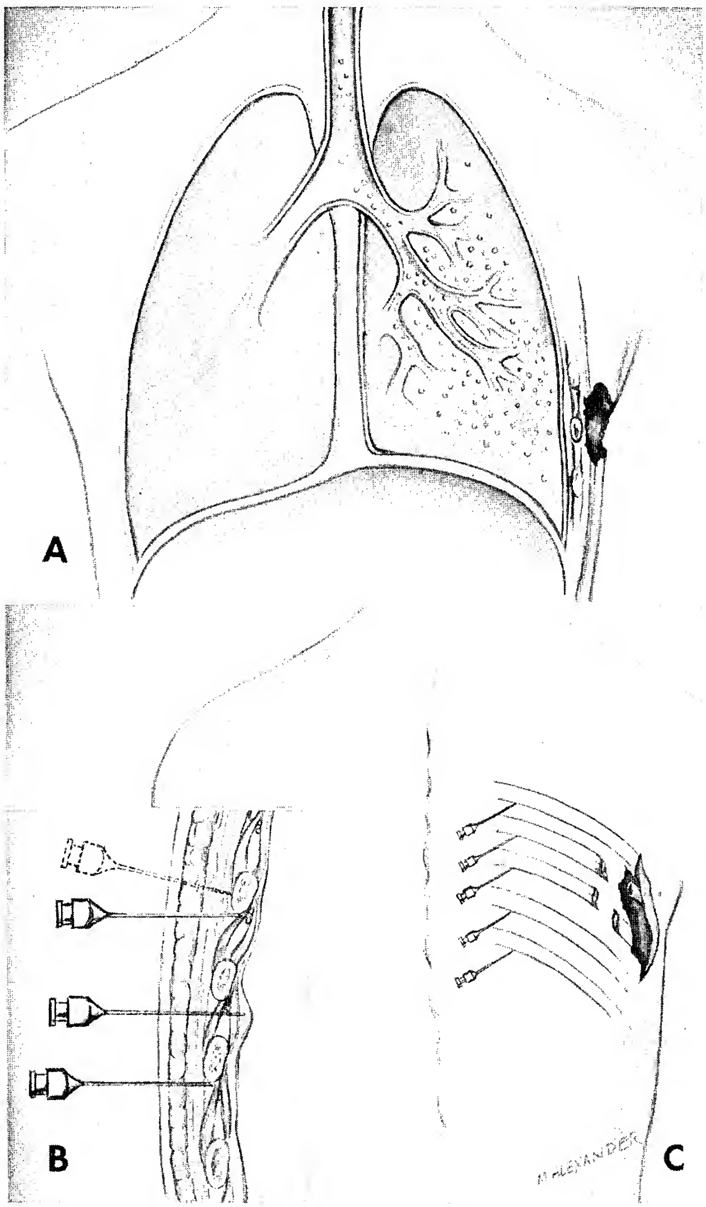


FIGURE 68.—Intercostal nerve block in management of painful wounds of chest wall. A. Schematic showing of effects of painful chest wall on retention of secretions and on effectiveness of cough. B. Infiltration of skin and muscles with procaine hydrochloride. Long needle is gently manipulated until the tip comes into contact with the rib. C. Injection of procaine hydrochloride (3–5 cc. of 1-percent solution) beneath rib four fingers from spinous process. Care is taken not to inject solution into intercostal vessels.

over the transverse processes. The best results were achieved when one or two ganglia cephalad to the area of involvement were also incorporated in the block.

The needle, without the syringe, was introduced perpendicularly through the skin until contact was made with the dorsal surface of the transverse process; it was seldom necessary to introduce it more than 4 centimeters. The rubber marking was readjusted on the shaft from 3 to 4 cm. from the skin surface before the needle was withdrawn slightly. Then, with its bevel directed medially, the needle was redirected anteromedially and passed just inferior or just superior to the transverse process. It was slid along the body of the vertebra to the depth indicated by the marker. At this location, the tip of the needle lay in the immediate vicinity of the sympathetic chain.

If, during its insertion, blood or spinal fluid appeared, the needle was withdrawn and was reinserted in a slightly different direction. If blood or spinal fluid did not appear, the syringe was attached to the needle, and aspiration was carried out in two planes, to be sure that the needle did not lie in a blood vessel, in a prolongation of the subarachnoid space, or in the pleural cavity.

If aspiration was negative, 6 cc. of 1-percent procaine hydrochloride solution was injected into the tissues. If the needle had been introduced correctly, relief from pain was almost immediate, only just enough time being required for infiltration of the solution through the tissues surrounding the sympathetic chain.

As soon as either intercostal or paravertebral nerve block had been accomplished, an attendant forced the patient to cough.

If open thoracotomy was necessary in a patient who had not previously been submitted to nerve block, advantage was taken of the opportunity to block the nerves under direct vision by injecting procaine hydrochloride solution. Crushing the nerves with a fine hemostat was a much less desirable procedure.

Results of nerve block.—Blocking out of the pain stimuli by injection of the intercostal nerves or by paravertebral block produced prompt and often dramatic results. Pain and discomfort almost invariably disappeared. The patient was willing to cough because it was no longer painful to do so, and evacuation of the fluids in the tracheobronchial tree was effected.

It was impossible to overlook the possible influence of nerve block on constriction of the bronchial tree and secretion of mucus. Clinical evidence supported the hypothesis of its role. Frequently, casualties were seen with respiratory distress that could not be accounted for by the severity of the thoracic injury, pain in the chest wall, shock, the presence of blood or other fluid in the bronchial tree, aspiration of gastric contents, infection, or exposure to noxious gases. Coughing was apparently free and forceful, but wheezing persisted, and sputum was not raised. Once the intercostal nerves were blocked, however, the picture changed. Wheezing disappeared promptly, and sputum was raised freely. The assumption in such cases was that reflex bronchial spasm probably played some role in the previous symptoms and signs.

Relief of pain and discomfort after intercostal nerve block lasted for varying periods of time but almost never for less than 24 hours. The block could be repeated as necessary, but frequently a single injection gave permanent relief. Why relief of pain extended beyond the period of the pharmacologic action of the drug is difficult to explain. Possibly relaxation of muscle spasm and improvement of the blood supply to the traumatized area played some part in the results.

The beneficial effect of paravertebral block usually lasted from 2 to 4 hours. One injection frequently gave permanent relief, and more than three were almost never necessary.

An effective nerve block, in addition to rendering anesthetic the area innervated by the somatic nerves blocked, sometimes also provided immediate relief of pain in a referred area, occasionally on the side opposite the trauma.

When the nerves were blocked at thoracotomy, the stimuli arising from the chest wall and parietal pleura were diminished, and the patient was usually free from pain during the most important part of the postoperative period. Nerve block at operation also eliminated the necessity for later intercostal nerve block.

Catheter Aspiration

If, after a reasonable period of time, a patient with traumatic wet lung did not improve under the measures just outlined, combined with the usual regimen of resuscitation, mechanical measures had to be employed. The circumstances of the individual case determined whether catheter aspiration (fig. 67E) should be tried or bronchoscopy (fig. 67F) resorted to at once. The length of the trial period, which might be as short as 5 or 6 hours or as long as 20 to 24 hours, depended upon the patient's original injury, his clinical status, the roentgenologic findings, and his progress under treatment. Some patients were too exhausted to cough effectively without aid, and some were uncooperative for other reasons.

Whether catheterization or bronchoscopy was used, the aims were the same:

1. To remove excess fluid in the lower airway.
2. To loosen deeper secretions by local manipulation.
3. To promote more efficient cough.

A long delay was not justified if the situation was complicated by a communication between the tracheobronchial tree and a pleural cavity containing fluid.

Catheter aspiration of the tracheobronchial tree had so many advantages that it was employed in all cases in which bronchoscopy was not clearly indicated (p. 227):

1. It was preferable to bronchoscopy in patients who were desperately ill but conscious. Experience showed that in such cases the manipulations required in bronchoscopy might be extremely dangerous.

2. Catheter aspiration was particularly valuable in acute emergencies which permitted no delay.

3. The equipment was almost always readily available from standard hospital supplies.

4. The technique was so simple that it could be readily mastered, in contrast to the elaborate training necessary in bronchoscopy.

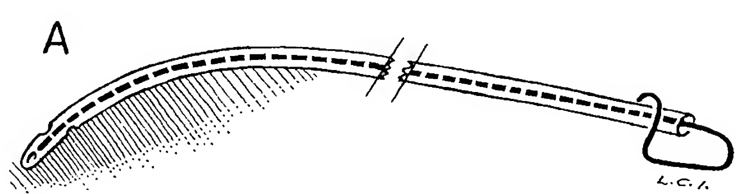
5. Catheter suction could be repeated as often as necessary.

Technique.—The technique generally employed for catheterization (fig. 69) was a modification of the method described by Haight (7) in 1938. Suction was usually provided by ordinary ear, nose, and throat suction machines, which delivered from 15 to 20 pounds of negative pressure. Connecting tubing and a Robinson ureteral catheter or a similar catheter, size No. 16 or No. 18, with one or two openings, constituted all the equipment necessary. If electricity was not available, as it sometimes was not in combat areas, an attachment to the windshield wiper or gas intake manifold of a motor vehicle served as an emergency source of power. The portable hand suction machine devised by Major Brewer was often used in forward installations in which electrical suction machines were not always at hand.

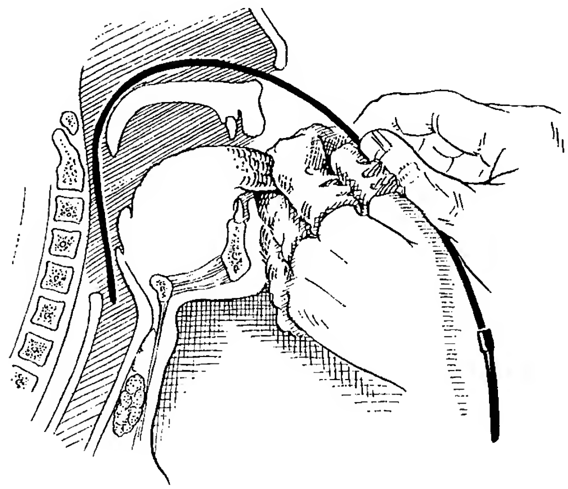
Anesthesia was not required unless the gag reflex was hyperirritable. Then 2 percent Pontocaine hydrochloride (tetracaine hydrochloride) or 5 percent cocaine was sprayed onto the pharynx and painted onto the hypopharynx with a curved swab or applicator. When local analgesia was necessary, a small dose of some barbiturate was given before it was applied, and fluids were withheld until the gag reflex had returned.

The patient was placed in the semi-Fowler position, with the neck flexed. If he was unconscious, the neck was fixed by supporting the raised head on a pillow or a folded blanket. If he was conscious, the tongue was pulled rather sharply forward, to anchor the larynx. Occasionally an epiglottis that was unusually flaccid so covered the larynx that catheterization was impossible without a laryngoscope to provide direct vision.

The catheter was introduced through the nostril and advanced until the larynx was reached. If the patient was unconscious, the index finger of the



FIGURES 69.—Technique of tracheobronchial catheter aspiration. A. Robinson type of rubber catheter after sterilization by heat on bent catheter guide, to provide for slight curve of tip. The catheter is sterilized in 70 percent alcohol or some similar sterilizing solution when it is used, to assure maintenance of curve.



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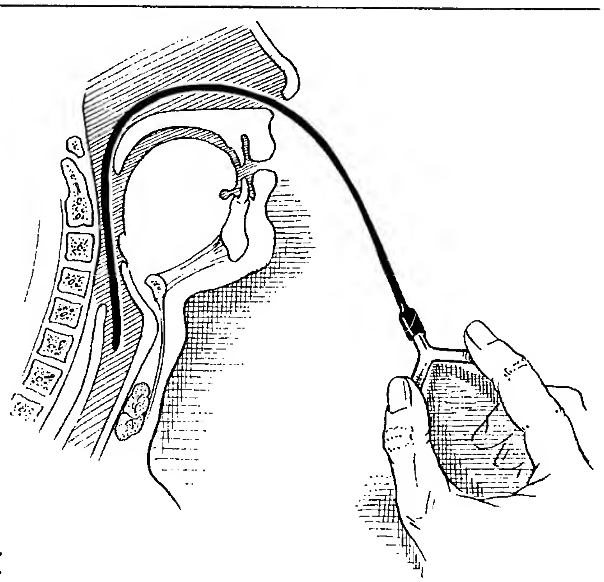

C

FIGURE 69.—Continued. B. Forward fixation of larynx with left hand, by holding tongue forward with gauze-covered fingers. With the right hand, the catheter is rapidly advanced through the nares and past the glottis as the patient inspires deeply. If he is comatose, a mouth gag is used, and the epiglottis is picked up with the left forefinger. The catheter is then guided through the larynx. C. Advancement of catheter into trachea by intermittent suction over Y-tube. Once it is in trachea, it is moved back and forth to stimulate coughing.

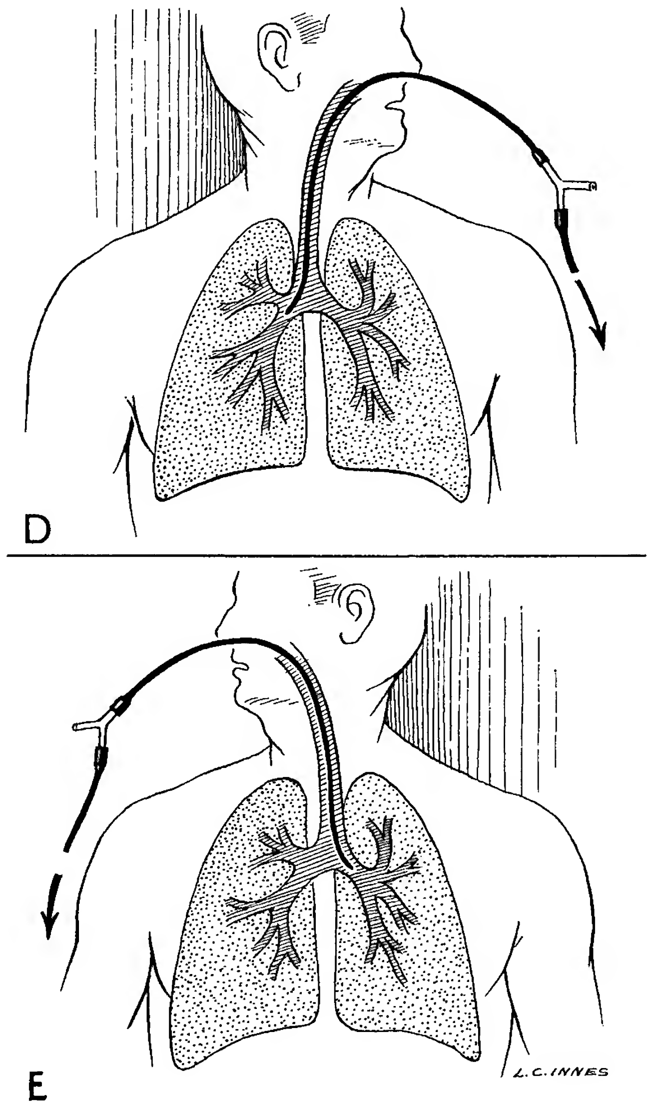

FIGURE 69.—Continued. D. Introduction of catheter into right main stem bronchus. When the patient's head is turned sharply to the left, the right stem bronchus is more directly in line with the trachea. The catheter is then advanced and intermittent suction employed. E. Introduction of catheter into left stem bronchus, by reversing the procedure described in D. The head is turned markedly to the right in this stage of the procedure.

left hand engaged the tip of the epiglottis, so that the catheter could be passed through the larynx without difficulty.

When the catheter had entered the larynx, it was withdrawn for about 1 centimeter. If the patient was conscious, he was asked to take a rapid, deep breath. During the inspiration, the catheter was quickly advanced into the trachea. In an occasional case, it was easier to introduce it during the expiratory phase of a cough. The successful entrance of the catheter into the trachea was signified by involuntary coughing, passage of air through the trachea, or sudden hoarseness. The irritation caused by the catheter was likely to stimulate all but moribund patients to cough, but hoarseness was the most certain indication that the catheter was in the trachea. Occasionally, when the tube had been accidentally introduced into the esophagus, a free flow of air about it simulated respiration. If the accident was not recognized and oxygen therapy was used, gastric dilatation of serious proportions might occur.

Suction was not applied until the catheter had been advanced into the trachea for several centimeters. When the manipulations were discontinued, the patient was urged to cough. This he usually did forcibly—in fact, he found it impossible not to—because of the stimulation of the tracheal mucosa by the catheter. Often more sputum was coughed up around the tube than was aspirated through it. Suction, coughing, and manipulation of the catheter were alternated until all portions of the tracheobronchial tree were apparently free of fluid. Continuous periods of suction never exceeded 5 seconds, and they were briefer if the patient seemed exhausted by them or if he became cyanotic.

It was simple to introduce the catheter into the right stem bronchus; the patient's head was merely turned well to the left. To enter the left stem bronchus was somewhat more difficult (vol. I). The head had to be turned far to the right and the chin elevated. The tube was advanced as far as possible into each stem bronchus. After aspiration, the patient was rolled on his side, with the more involved lung uppermost, to permit drainage of the small bronchi by gravity.

After catheter aspiration, most patients coughed with greater efficiency because of the improved ventilation of the pulmonary tree. Because of the absence of appreciable trauma to the larynx or bronchi, the procedure could be repeated as often as every 2 to 3 hours if this was necessary. In the occasional case, bronchial secretions and pulmonary transudates formed with such rapidity that aspiration was necessary at 30-minute intervals. In such cases, the catheter was left in the trachea, sometimes from 8 to 12 hours. When this was necessary, 100 percent oxygen was administered continuously through the catheter between aspirations, at the rate of 1 to 2 liters per minute.

Bronchoscopy

Bronchoscopy played a valuable role in the management of war wounds of the chest. At no time was its use routine. It was properly considered a highly technical procedure, requiring skill and experience for its safe use and

to be used only on definite indications. It was made more widely available as the war progressed, however, because thoracic surgeons already trained in its use taught the technique to selected general surgeons and qualified anesthesiologists.

The decision to employ bronchoscopy rather than catheter aspiration was made on the indications of the individual case. It was sometimes preceded by a trial of catheter aspiration but in other instances was resorted to immediately. Its chief advantage over catheter suction was that it was more thorough. Because both stem bronchi were visualized, aspiration could be carried out with more assurance that all secretions and obstructing mucous plugs had been removed. When it was indicated, bronchoscopy also permitted the direct application of procaine hydrochloride, cocaine, or epinephrine solutions to the swollen bronchial mucosa. The resulting shrinkage of the mucosa further increased the lumen of the airway.

Indications.—No hard-and-fast rules were formulated, but in general, bronchoscopy was regarded as the procedure of choice in wet lung under the following circumstances:

1. When tracheobronchial aspiration by catheter had been ineffective because of failure of the lung or segments of the lung to reexpand with positive pressure, and moisture persisted in the chest.
2. When mucous plugs or blood clots were thought to be present in the branch bronchi.
3. When obstruction of the trachea or bronchi had been present for a considerable time. Under these circumstances, sudden loosening of large amounts of secretion from the obstructed bronchus might flood a normal bronchus, with grave consequences.
4. When the cough was weak and ineffectual and there was danger of flooding the contralateral bronchus by sudden release of large amounts of secretion.
5. When a patient was admitted to the hospital completely exhausted, with the tracheobronchial lumen brimming with secretions that he did not have the strength to cough up. In this type of patient, bronchoscopy was mandatory. In fact, the more critical his condition, the more urgent was the indication.
6. When lobar or total pulmonary atelectasis had occurred, because of the dangerous reduction in the vital capacity.
7. When bronchial obstruction recurred in spite of repeated tracheobronchial catheter aspirations. The cause of the obstruction was usually incomplete removal of obstructing material by catheter suction.
8. When vomitus had been aspirated, or was thought to have been aspirated, into the lungs. This was an imperative indication, because of the highly deleterious effect of gastric secretions on bronchial and pulmonary tissue.
9. When emergency thoracotomy was necessary. Bronchoscopy immediately before operation, in addition to emptying the tracheobronchial tree and

improving the cardiorespiratory status, made the administration of the anesthetic simpler and safer.

Techniques.—The standard technique of bronchoscopy was employed. The procedure was usually carried out in the operating room but could be performed by a skilled bronchoscopist without moving the patient from the stretcher or bed.

General anesthesia was contraindicated if there was an unusual amount of fluid in the tracheobronchial tree. Topical analgesia was employed in most cases, but in numerous semicomatose or apparently moribund patients, no anesthesia was used. Oxygen (100 percent) was administered continuously to all patients who showed any evidence of anoxia.

The operation was performed as rapidly as possible, so that a severely wounded patient, in shock, would not be exposed to the fatiguing effects of prolonged coughing.

Some surgeons, after the trachea and main bronchi were cleared, palpated the chest carefully, in an endeavor to find secretions still in situ in spite of apparently successful aspiration. When such areas were found, the tip of the aspirator was applied directly to the orifice of the affected lobe, to excite coughing and raise the remaining secretions.

Oxygen Administration

Oxygen inhalations by means of the nasal catheter or the Boothby-Lovelace-Bulbulian mask were used promptly whenever cyanosis accompanied wet lung or dyspnea was severe. Some patients were disturbed at first by the face mask, but with sufficient encouragement, they all became reconciled to its use.

If moisture persisted in the lungs after intercostal nerve block and catheter aspiration or bronchoscopy, the oxygen was delivered under positive pressure (figs. 67G and 70). This was a technique described by Barach and his associates (*8*) shortly before the war, to relieve the pulmonary edema associated with pneumonia, gas poisoning, and cardiac disease. When the technique was first applied to combat-incurred wounds in the winter of 1943–44, considerable difficulty was encountered. A simple and effective solution of the problem was the use of a to-and-fro anesthetic system, with a soda-lime canister and rebreathing bag. Positive pressure was maintained manually on the bag, care being taken to avoid pressures higher than from 2 to 6 cm. H_2O. Pressures as high as 10 cm. H_2O or more were dangerous; they could cause a considerable rise in venous pressure; a fall in systolic, diastolic, and mean blood pressures; and a decreased blood flow.

Fluid that was constantly forming in the alveoli and bronchioles could not be completely removed by suction, but suction, with nerve block and the other measures described, removed enough fluid for oxygen under positive pressure to keep the bronchioles patent. The use of oxygen under pressure also opposed the hydrostatic pressure of the blood in the capillaries and increased the vital capacity. If the lungs were not too severely damaged and if shock, tension

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FIGURE 70.—Administration of oxygen under intermittent positive pressure in management of wet lung, Cassino, Italy, 1943. A. Administration with portable circle filter anesthetic machine: Face mask; tubes in circle filter; respiration bag, which was manually compressed to supply positive pressure oxygen to face mask; portable anesthetic machine with circle filter and soda-lime canister; water manometer to determine amount of positive pressure; and large oxygen tank.

pneumothorax, and other adverse factors could be controlled, this method was practically always successful in drying up wet lung caused by tracheobronchial transudation and exudation. It was of particular value when an excessive and injudicious use of blood and plasma was a contributory factor in the edema and when ventricular failure was impending.

Oxygen was sometimes administered under positive pressure in the early stages of traumatic wet lung. Its prophylactic value was thought to be consid-

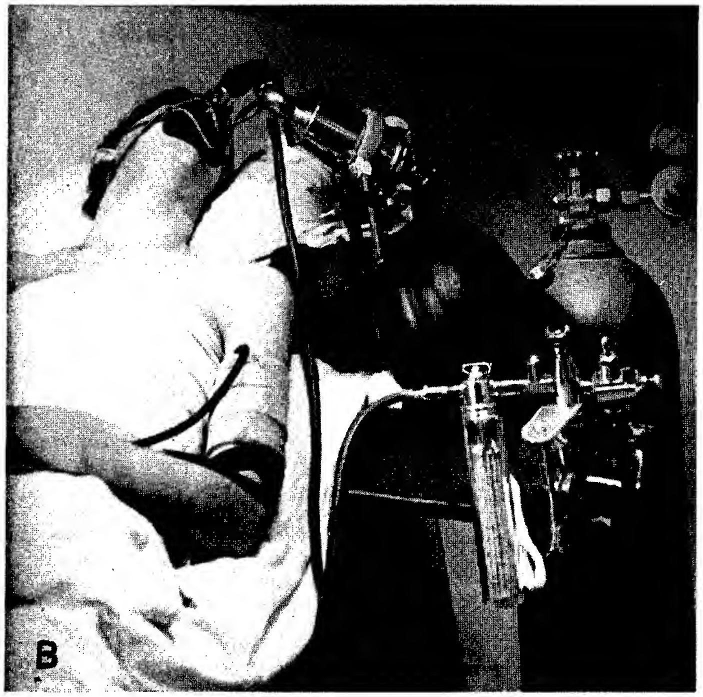

FIGURE 70.—Continued. B. Administration with portable to-and-fro soda-lime canister anesthetic machine: Face mask; soda-lime canister; respiration bag, which was manually compressed to supply positive pressure oxygen to face mask; portable anesthetic machine with valves and bubbler for ether (only water was used in oxygen therapy); and oxygen tank.

erable, but the indications for its employment on this indication did not become fully established during the war.

Other Measures

Atropine administration.—If moisture continued to be present in the lungs and vigorous measures to empty the tracheobronchial tree proved ineffective, atropine was sometimes given intravenously, in $\frac{1}{100}$- gr. doses. If reflex-spasm of the bronchus were initiated by thoracic injury, as the experimental work of de Takats and his associates (*2*) had suggested, one might expect atropine to abolish vagal reflexes and reduce tracheobronchial secretions. De Takats himself, however, found that this method prevented bronchospasm in less than half of his experimental animals, even when amounts up to gr. $\frac{1}{8}$ were employed. Atropine was not widely used during the war, and the clinical experience with it was too conflicting to permit any definitive statements concerning its value except that when wet lung was fully developed, this drug was not effective.

Carbon dioxide inhalations.—Carbon dioxide inhalation was another controversial measure occasionally employed in wet lung. This gas is a true expectorant, and hyperventilation with it had the mechanical effect of loosening viscid secretions and propelling them upward along the tracheobronchial lumen. If hypoxia was present, most observers regarded the method as equivalent to whipping a tired horse.

The preferred method was to use 100 percent carbon dioxide and to administer it by means of a catheter and small funnel as the patient took two or three deep breaths. Forced coughing during and following the brief period of hyperpnea thus produced was of the greatest importance and was not always sufficiently stressed. Unless the patient coughed, the method lost much of its effectiveness. If carbon dioxide was not available, rebreathing into a paper bag was often employed as a substitute, usually very effectively.

RESULTS OF THERAPY

Once proper measures had been instituted to relieve pain in the chest wall, clear the airway, and permit effective coughing, the entire picture of a patient with wet lung usually changed promptly. Results were often dramatic. A cyanotic, comatose patient, with wet, rattling respirations, often became alert and oriented, with good color and almost normal respirations, within a matter of minutes.

Once the wet lung was controlled, it was possible to evaluate the primary injury. Hemothorax, shattered ribs, and the shell fragment in the lung looked less ominous and often seemed less urgent. The lung had been restored to normal, or almost normal, capacity to cope with the injury or with the surgery required to correct the injury. Evaluation of the total patient was possible, in short, under circumstances which permitted a deliberate rather than a frantic approach to the problem.

An undoubted result of the recognition and vigorous management of wet lung was apparent in the Mediterranean theater in a number of respects, including (1) the low case fatality rate and low morbidity of chest injuries, (2) the infrequency of lung abscess after injury, and (3) the almost complete absence of massive atelectasis.

CASE HISTORIES

The following case histories illustrate a number of the points in the foregoing discussion of traumatic wet lung:

Case 1.—A 23-year-old sergeant was received in an evacuation hospital 3 hours after he had sustained penetrating wounds of the chest and buttocks from a high explosive shell fragment. The pulse was 110, the respiration 30 and noisy, and the blood pressure 110/80 mm. Hg. The patient was extremely dyspneic and complained of severe pain in the chest and abdomen.

Evidence of a large amount of fluid in the left chest almost obliterated all other physical findings. Loud musical wheezes were heard over the right chest anteriorly and posteriorly. Roentgenologic examination confirmed the presence of fluid in the left chest. The

left eighth rib was fractured, and a small foreign body was seen above the left diaphragm behind the heart.

Morphine (gr. 1/4) and atropine (gr. 1/100) were given by vein. The pain was somewhat relieved, but not enough to permit effective coughing. Complete relief followed blocking of the fifth through the tenth left intercostal nerves. The patient immediately coughed up a large amount of mucus mixed with fresh and old blood, after which he was able to breathe deeply and without discomfort. The lungs were dry on auscultation. Debridement of the chest wall was then carried out without difficulty under Pentothal sodium (thiopental sodium) anesthesia.

The patient continued to raise bloody sputum for a week, but there was no reaccumulation of fluid in the tracheobronchial tree and no recurrence of chest pain. After a total of 2,730 cc. of bloody fluid had been removed from the left chest by repeated thoracenteses, the left lung was almost completely reexpanded, and the remainder of the patient's convalescence was uneventful.

Comment.—In this case, retention of blood in the bronchial tree as the result of intrapulmonary hemorrhage was chiefly responsible for the wet lung, though an excess of mucus was also a factor. Severe chest pain, which prevented effective coughing, was not relieved by a large dose of morphine but was promptly relieved by blocking the appropriate intercostal nerves. Immediately thereafter, the patient, by his own efforts, raised the blood and mucus that had accumulated in the tracheobronchial tree, and recovery was without further complications.

Case 2.—A 21-year-old sergeant was received in a field hospital in severe shock 3 hours after he had sustained a sucking wound of the left chest and penetrating wounds of the right chest, thigh, forearm, hand, and cheek. The pulse was 140, and the blood pressure could not be obtained. Breath sounds were diminished on the right side of the chest, and signs of fluid were elicited on the left side.

The patient had had no medication since he was injured and was in severe pain. He was therefore given morphine gr. 1/8 by vein after an occlusive dressing had been placed over the sucking wound. Pain was completely relieved after a second injection of morphine, in the same amount and also by vein, but only small quantities of bloody sputum were raised. After the administration of two units of plasma and 500 cc. of blood, the pulse fell to 132 and the blood pressure was 104/80.

Two hours later, the patient's condition suddenly became critical. He was comatose and cyanotic. The pulse was weak and thready. Rales were audible in the trachea. Catheter suction was instituted at once, and large amounts of frothy yellow sputum were aspirated. The response to this measure was dramatic. The patient immediately regained consciousness, and his color and pulse improved. The catheter was kept in place for 8 hours, and suction was repeated every 20 to 30 minutes. Between aspirations, 100 percent oxygen was administered through the catheter.

At the end of 8 hours, during which time the patient's condition steadily improved, roentgenograms of the chest showed fluid in the left chest and foreign bodies in both lung fields. Since the tracheobronchial tree was now apparently dry, the catheter, which meantime had slipped into the right main bronchus, was removed. After a transfusion of 500 cc. of blood and a unit of plasma, 100 cc. of air and 200 cc. of bloody fluid were aspirated from the left chest.

Seventeen hours after admission, when the blood pressure had reached 108/74 mm. Hg, bronchoscopy produced a considerable amount of bloody fluid from both main bronchi. Careful inspection showed that the prolonged intubation had apparently caused no trauma to the larynx or the trachea.

Immediately after bronchoscopy, operation was done under intratracheal ether-oxygen-anesthesia. It included debridement of the sucking wound of the chest wall; ligation of the internal mammary vessels, which were lacerated though not actively bleeding; suture of the laceration of the upper lobe of the left lung; removal of several small metallic foreign

bodies from the pericardium and another from the right chest wall; and intercostal drainage. A foreign body in the lower lobe of the left lung and another in the right lung were left in situ. While the chest operation was in progress, another surgical team debrided the other wounds. At the conclusion of the operation, bronchoscopy was repeated, and a moderate amount of bloody mucus was aspirated from both stem bronchi. The patient received a unit of plasma and 500 cc. of blood during the operation.

The immediate postoperative status was satisfactory. The following day, the patient became disoriented, presumably as the result of cerebral anoxia, though he had been receiving oxygen continuously, by nasal catheter, since operation. The temperature was 99.4° F., the pulse 150, and the respiration 48. Coughing produced thin yellow fluid, but the pulmonary tree appeared to be filling up with moisture.

Tracheobronchial aspiration by catheter somewhat improved the patient's critical condition. Tracheal rhonchi and coarse bronchial rales disappeared, but medium and fine rales could still be heard diffusely over all lobes of both lungs. Fluid was apparently being formed more rapidly in the peripheral portions of the pulmonary tree than it could be removed by natural processes. Since the clinical picture resembled that seen in pulmonary edema accompanying heart disease and gas poisoning, positive pressure oxygen was begun. Within 15 minutes, a notable improvement occurred. The pulse fell to 120. The respirations fell to 32 and became considerably less labored. Only a few fine rales could be heard at the bases of both lungs. At this point, positive pressure oxygen was discontinued, and administration by the Boothby-Lovelace-Bulbulian mask was resumed.

During the next 24 hours, the patient had two additional attacks of pulmonary edema, each one resembling the acute attack just described. In each one, the effect of oxygen administration under mild positive pressure was as striking as in the first attack. Recovery thereafter was uneventful.

Comment.—This case is a striking example of the therapeutic problems presented by traumatic wet lung in a patient with multiple chest and other wounds. Immediate tracheobronchial catheter aspiration, intratracheal oxygen administration, and cautious fluid replacement over an 8-hour period made this soldier a suitable candidate for surgical closure of a sucking chest wound and the intrathoracic surgery required. Bronchoscopy just before operation aided in the maintenance of a patent airway during operation, and its repetition at the conclusion of the procedure simplified the first 24 hours of the postoperative course. Three attacks of apparently true pulmonary edema over the next 48 hours were controlled by the administration of oxygen under mild positive pressure. Why edema developed in this case after operation is not clear, but anoxia caused by severe trauma to both lungs was probably an important factor, as was tracheal obstruction from mucus and blood.

There seems little doubt that this patient survived because of the therapy instituted for the control of the wet lung that followed his combat-incurred injuries, one of which was a sucking wound of the chest.

Case 3.—A 27-year-old lieutenant sustained a sucking wound of the chest that was treated immediately by an occlusive dressing and 24 hours later by suture; the skin was left open. For the next 3 days, small amounts of pure blood were expectorated.

When the patient was admitted to a thoracic surgery center 5 days after wounding, he was comfortable while at rest but moderately dyspneic on exertion. The cough was wet but was productive of only small amounts of blood-tinged mucoid sputum. A few coarse rales were heard parasternally on the right. Roentgenograms taken the following day showed a right-sided hydropneumothorax without cardiac shift. Aspiration of the chest on the second and third days after admission produced 360 cc. and 390 cc., respectively, of old blood and air from the right pleural cavity. On each occasion, highly negative intrapleural pressure prevented further aspiration.

The patient's wet cough continued in spite of these thoracenteses, frequent changes of position, and the administration of carbon dioxide. On the third day after admission,

roentgenograms of the chest showed a minimal residual hemopneumothorax, an expanded upper lobe, and atelectasis of the middle and lower lobes on the right side. Bronchoscopic aspiration, instituted immediately, produced large amounts of blood clots and mucus, amid which partly formed bronchial and bronchiolar casts were discernible. Roentgenologic examination 18 hours later showed almost complete reaeration of the atelectatic lobes. The cough became loose and remained productive for 4 days after bronchoscopy, then ceased altogether. On the 12th day after wounding, roentgenograms showed the right lung to be completely expanded and almost normal in appearance.

Comment.—In this case, although roentgenologic evidence of atelectasis was obscured in the first roentgenograms by the overlying hemothorax, certain points in the history and physical findings pointed to the diagnosis. They included continued wet cough with inadequate expectoration, extensive pneumothorax without cardiac shift, and the development of pronounced evidence of negative pressure after aspiration of relatively small amounts of fluid from the pleural cavity. The aspiration of old blood clots and mucus by bronchoscopy resulted in the prompt reestablishment of a patent airway and prompt reexpansion of the lung.

Earlier attention to the wet lung in this case would have permitted the use of simpler methods of management and might have prevented the development of the complicating atelectasis.

Case 4.—When this patient was seen 2 hours after he had fallen off a motorcycle, he was complaining of severe pain in the left chest and dyspnea. He had a paroxysmal, ineffectual wet cough. There was extreme tenderness over the left fifth and sixth ribs, and a flail segment in this area was undergoing paradoxical oscillations. Numerous wheezes and rhonchi were present bilaterally. Roentgenologic examination revealed anterior and posterior fractures of the left fifth and sixth ribs.

Intercostal block of the third through the ninth ribs, which resulted in only partial relief of pain, was supplemented by paravertebral block of the sympathetic ganglia of the same segment. Pain was promptly relieved, and paradoxical oscillations of the flail segment ceased. There was still some moisture in the lung, but the remaining wheezes and rhonchi disappeared, and respirations became entirely normal, within 5 minutes after the intravenous administration of $\frac{1}{150}$ gr. of atropine sulfate.

On the third day after wounding, a moderate recurrence of pain and wetness was immediately controlled by repetition of the paravertebral block.

Comment.—This case well illustrates the effectiveness of nerve block in the management of flail chest of limited extent, as well as the (occasional) effectiveness of atropine as an adjuvant measure in the control of wet lung.

Case 5.—This patient was seen in a shock tent on 4 February 1944, 43½ hours after wounding. He had sustained a penetrating wound of the left anterior chest and was complaining of hemoptysis; dyspnea; a painful wet cough; and pain in the left shoulder, left chest, and hepatic area. He was in critical condition, extremely dyspneic and cyanotic, and showers of moist rales were heard throughout both lungs. Examination also revealed tenderness and rigidity in the left upper quadrant of the abdomen. Roentgenologic examination revealed a retained missile in the region of the left diaphragm and an extensive pathologic process in the left lung and left pleural cavity.

An hour after the patient had been received in the shock tent, intercostal block of the left fourth and fifth intercostal nerves was carried out, and 200 cc. of air and blood were aspirated from the left pleural cavity. There was immediate improvement in the pain, dyspnea, and cyanosis originally present. The left upper quadrant of the abdomen was no longer rigid. There was also an improvement in the wet lung. Two hours later, the patient again complained of pain, and there was a recurrence of the pulmonary difficulties. A paravertebral sympathetic block (D4–9) was immediately performed, and a large amount of blood and mucopurulent sputum was aspirated through a tracheal

catheter. Pain was promptly relieved, and pulmonary moisture was greatly reduced. Shortly afterward, the wound was debrided.

Recovery was smooth except for slight pain and moderate dyspnea the day after operation. Both symptoms were promptly relieved by intercostal block of the fifth through the ninth intercostal nerves. A week after his admission, the patient was so much improved that he could be evacuated.

Comment.—When this patient was first seen, his condition was so critical that it did not seem that he could possibly survive. Nerve block effected considerable improvement, but when his pulmonary difficulties recurred, he seemed so exhausted that mechanical aspiration of the tracheobronchial tree was resorted to at once. In this case, the correction of wet lung was clearly lifesaving.

Case 6.—A 21-year-old soldier, injured in an automobile accident, complained of hemoptysis, persistent pain on coughing, and pain on deep breathing. When he was admitted to a thoracic surgery service 48 hours after the accident, he was dyspneic and complained of discomfort and pain in the left lower chest. There was no external evidence of injury. The percussion note was resonant bilaterally, but there were diffuse wheezes and rhonchi throughout both lungs. Pain was so severe that coughing was impossible, in spite of urging. Pressure over the seventh, eighth, and ninth ribs in the left anterior axillary line elicited exquisite tenderness, but rœntgenograms of the chest revealed no abnormalities.

In spite of failure to demonstrate any rib fractures, an intercostal block of the area of tenderness completely relieved the pain. Shortly afterward, the patient coughed up several tablespoonsful of thick, white, tenacious mucus. Two hours later, physical examination revealed entirely normal findings in both lungs. Recovery was uneventful thereafter.

Comment.—In this case, nerve block permitted effectual coughing by relieving the pain that had prevented it previously. There was only mucus in the tracheobronchial tree, and it may be that this is an instance of an abnormally large secretion of mucus because of reflex stimulation via the intercostal nerves. If this reasoning is correct, one effect of the nerve block may have been to reduce the secretion of mucus.[2]

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[2] The reader is referred to chapter XI (p. 441) for long-term followup studies on casualties whose chest wounds were complicated by the wet lung syndrome.

CHAPTER VI

Hemothorax and Hemothoracic Empyema

Thomas H. Burford, M.D.

GENERAL CONSIDERATIONS

At the beginning of World War II, there was little or no realization of the fact that hemothorax was the most frequent, and probably the most important, complication of wounds of the chest. A brief experience with these wounds, however, compelled the recognition of both its frequency and its importance. The principles and techniques by which hemothorax was managed influenced the entire scheme of the treatment of chest wounds from forward hospitals through chest centers.

In view of these facts, it is surprising to find that hemothorax had attracted very little attention before World War II. Surgeons who dealt with it at all were divided into two schools. One group maintained that absorption of the sanguineous intrapleural material would invariably take place, and with reasonable promptness. The other group advocated the prompt evacuation of the pleural cavity, on the premise that blood, by its mere presence, was harmful. Even those who did not accept the theory that all hemothoraces were absorbed by natural processes believed that this occurred in 90 to 95 percent of all thoracic wounds.

When the literature of the prewar period is examined, one cannot fail to be impressed with the small number of observers who concerned themselves with the fate of the 5 or 10 percent of patients whose hemothoraces were not absorbed. This lack of concern was evident in the military manual on thoracic surgery issued in 1943 under the auspices of the American Association for Thoracic Surgery and the National Research Council (*1*). Blood in the chest, according to this manual, tends to remain fluid, probably because it is defibrinated by the motions of the lungs and the heart. A section was devoted to the management of infected hemothorax, but no recommendations were made for dealing with the exceedingly important complication of clotted hemothorax. The omission was typical. It was also unfortunate. The casualties whose hemothoraces clotted or did not absorb for other reasons constituted the group who developed empyemas that tended toward chronicity and who presented encased lungs or contracted hemithoraces, with resulting impairment of respiratory function.

Until articles on unabsorbed hemothorax began to be published from the Mediterranean Theater of Operations, U.S. Army, in World War II, not many observers even mentioned the possible clotting of blood in the pleural cavity.

It is also startling, in retrospect, to find in the prewar literature almost no effort to distinguish postpneumonic and metapneumonic empyema from post-traumatic empyema, although the latter variety, if not correctly managed, gives rise to a far higher incidence of chronicity. Both varieties were discussed as if they were of the same origin and had the same characteristics. Studies on hemothorax as an antecedent to empyema were remarkable for their paucity.

The recognition of hemothorax as perhaps the most important complication of wounds of the chest was a development of World War II. Had the prewar laissez-faire approach to it been carried over into military surgery, it would have resulted in an intolerably high rate of pleural sepsis in World War II.

Nomenclature.—Before proceeding with the discussion of hemothorax and its sequelae, it is necessary to define the meaning and implications of the terms used for this condition in World War II:

The term "simple hemothorax" implied the presence of blood in the pleural cavity, without complicating features. This term was used whether the blood was the result of injury to the chest wall alone or was the result of a penetrating or a perforating wound.

The term "infected hemothorax" implied the presence of bacteria in the pleural fluid, plus the clinical manifestations of their presence.

The term "chronic hemothorax" or "chronic traumatic hemothorax" was used to indicate any collection of blood in the pleural cavity that could not be reduced by thoracentesis. The term implied that fresh blood had ceased to enter the pleural space, that hemostasis had been achieved, and that the collection of blood was therefore residual. A chronic hemothorax was usually an organizing hemothorax. It was the clotting of the blood plus its inevitable sequela, organization, that made aspiration no longer possible. A neglected accumulation of intrapleural blood that could be satisfactorily aspirated was not considered chronic because it could be evacuated at will by proper treatment.

There was general agreement that the term "chronic hemothorax" was both inadequate and misleading. It did not indicate, or even suggest, the really important element in the pathologic process. This element was the presence of fibrin, whether it was derived from blood spilled into the pleura, or from exudate formed by the pleura, or had been deposited in some other manner. Some such term as "fibrothorax" would have been more expressive and more correct, but the term "chronic traumatic hemothorax" began to be used, and semantic changes were not practical in wartime.

INCIDENCE OF HEMOTHORAX AND ITS COMPLICATIONS

Hemothorax.—Statements concerning the incidence of hemothorax in combat-incurred wounds of the chest are necessarily imprecise. Probably every casualty with a perforating or a penetrating thoracic wound had a hemo-

thorax of some degree. In a certain proportion of injuries, perhaps 15 or 20 percent, the collection of blood was so small as to cause no clinical manifestations, and it was rapidly absorbed by natural processes.

Various studies from the hospitals in the Mediterranean theater, including the chest centers, show the incidence of hemothorax to range from 80 to 84 percent. Well over half of the casualties received in field hospitals after wounding already had enough blood in the pleural cavity to make its removal an urgent part of the effort to restore the cardiorespiratory equilibrium. More significant than the high initial incidence is the fact that about three-quarters of the casualties received in base hospitals arrived with sufficient intrapleural blood to require treatment.

In the great majority of hemothoraces, once the policy of early and complete thoracentesis had been established, recovery was prompt and uncomplicated in the absence of complications from other components of the thoracic injury. In 752 hemothoraces treated at the 300th General Hospital chest center in the Mediterranean theater, between 1 April and 20 December 1944, by Maj. Thomas H. Burford, MC, and Maj. (later Lt. Col.) Edward F. Parker, MC, there were no complications in 603 of 678 cases in which the blood could be removed by aspiration. The average time required for complete clearing of the chest was from 10 to 14 days, and the average number of thoracenteses required was from 3 to 4.

Clotting and organization.—The hemothoraces that gave rise to difficulties were those in which clotting occurred. Exactly how often this happened, it is not possible to say. During the Italian campaign, some forward hospitals reported incidences of clotting ranging to 25 and 30 percent. These levels are exceptionally high. In one or two later studies, the incidence was 9 or 10 percent, which is rather low. Clotting probably occurred in about 15 percent of all hemothoraces, even when thoracentesis was undertaken early and was repeated as necessary.

The incidence of clotting naturally varied with circumstances. It was more frequent in severe wounds. It was also more frequent the longer thoracentesis was delayed. A casualty who was brought promptly to a hospital near the frontline and whose chest was evacuated as part of the regimen of resuscitation seldom developed an organizing hemothorax.

In nearly all instances of extensive clotting, some degree of organization of the clot followed. Infection, with its clinical manifestations, could and did occur in many unclotted hemothoraces, but it was much more likely to occur in large clotted collections. Two other consequences of clotting were also serious:

1. If an organizing hemothorax was of any size, simple removal of the clots at thoracotomy or attempted evacuation of the pleural cavity by water-seal intercostal drainage practically always proved inadequate, and the resulting pulmonary reexpansion was entirely unsatisfactory.

2. If expectant treatment was employed in organizing hemothorax, the period required for resolution was always prolonged. In one group of 13 patients observed late in the war, the total time for clearing ranged from 41 to 125 days and averaged 78 days. Clotting of a hemothorax was therefore an important cause of prolonged morbidity.

Infection and hemothoracic empyema.—Most infected hemothoraces were preceded by clotting, and most posttraumatic empyemas were preceded by infected hemothoraces. There was seldom any doubt of the sequence of events. In a small number of cases, even uninfected organizing hemothoraces produced extreme degrees of respiratory crippling, though the worst of these cases did not compare in severity with the crippling observed in patients in whom infection of a hemothorax had been permitted to become chronic. During World War I, chronic empyema was the most frequent complication of chest wounds (*2*). Almost a quarter of the thoracic casualties died, and from 25 to 30 percent developed empyema. If these same proportions had prevailed during World War II, the results of chest wounds would have been disastrous.

In the early months of fighting in North Africa, before the management of hemothorax had been standardized, the incidence of empyema was high, running to 25 or 30 percent in some hospitals. Even in the chest center at the 53d Station Hospital, Bizerte, which was equipped and staffed for the specialized care of chest injuries, it was 22.6 percent. By the end of the war, the general incidence in the theater did not exceed 10 or 11 percent, and more than one hospital had achieved an incidence as low as 7 percent. In the European Theater of Operations, U.S. Army, which had the early experience of the Mediterranean theater to guide it, chronic hemothoracic empyema was also infrequent.

An incidence of even 7 percent is much higher than the incidence of empyema after chest wounds in civilian practice. The explanation of the difference is simple: In civilian life, the agents of wounding are usually ice picks and bullets, which have a limited and localized destructive capacity. In combat-incurred injuries, on the other hand, while bullets were frequently as innocuous from this standpoint as they are in civilian life, most wounds were large wounds, and tissue destruction was extensive. Moreover, in combat-incurred wounds, the missiles often carried with them into the chest fragments of fractured ribs, bits of clothing, and other debris. Retained metallic foreign bodies, unless they were very large, played no significant role in most intrapleural infections (p. 327).

In World War II, the factors most frequently responsible for posttraumatic empyema were delayed and inadequate evacuation of the pleural cavity, inadequate debridement, inadequate drainage of the pleural cavity, and excessively prolonged treatment by aspiration and instillation of penicillin when it was obvious that radical therapy was required. The necessary interruption of professional supervision of casualties in the chain of evacuation was probably responsible for a small number of cases early in the war. How serious a part

inadequate early treatment plays in the development of empyema is evident in figures reported by d'Abreu (*3*): When the British evacuated 88 soldiers of all nationalities who had been engaged in guerrilla warfare in Yugoslavia and who had had no early surgical treatment for their chest wounds, they found that 48 of them had empyema.

The reduction in the incidence of posttraumatic empyema as the war progressed was the result of several factors, the most important of which was the increasing emphasis put upon early, complete evacuation of the pleural cavity, which was followed by prompt reexpansion of the lung. The advent of penicillin, with its beneficial effect on residual infection, also played a part. Penicillin represented an improvement over the sulfonamides, but it was not the major factor in the improvement. The most important single factor in the lowered incidence of posttraumatic empyema was the improvement in the surgery of chest wounds that came to pass with the increased experience of general and thoracic surgeons and of anesthesiologists.

Figures for empyema supplied by the Medical Statistics Division, Office of The Surgeon General, appear in tables 13 and 14. In connection with table 13, attention is called to the fact that data available only for 1944 and 1945

TABLE 13.—*Admissions for empyema of the chest in the U.S. Army, by area and year, 1942–45*

[Preliminary data based on sample tabulations of individual medical records]

[Rate expressed as number of admissions per annum per 1,000 average strength]

Area	1942–45		1942		1943		1944		1945	
	Number	Rate	Number	Rate	Number	Rate	Number	Rate	Number	Rate
Continental United States	406	0.03	121	0.05	175	0.03	75	0.02	35	0.01
Overseas:										
Europe	100	0.02	2	0.02	13	0.05	20	0.01	65	0.03
Mediterranean [1]	14	.01			5	.01	9	.01		
Middle East	4	.03			4	.08				
China-Burma-India	1	.00					1	.01		
Southwest Pacific	15	.01	1	.01	2	.01	7	.01	5	.00
Central and South Pacific	25	.02	2	.01	11	.04	7	.02	5	.01
North America [2]	20	.04	5	.05	11	.06	4	.03		
Latin America	4	.01	2	.02	2	.02				
Total overseas [3]	201	0.02	12	0.02	48	0.03	51	0.01	90	0.02
Total Army	607	0.02	133	0.04	223	0.03	126	0.02	125	0.02

[1] Includes North Africa.
[2] Includes Alaska and Iceland.
[3] Includes admissions on transports.

show that the incidence of empyema during this period was nearly six times higher than the number of admissions due to the condition.[1]

For 1944 (table 13), preliminary tabulations of individual medical records showed 126 admissions and 805 secondary cases of empyema. The figure for the secondary cases was derived from a 20-percent sample, consisting of 161 punchcard records. One-third of the cases of empyema occurred among admissions in the Zone of Interior and two-thirds among admissions overseas. In the latter group, more than 70 percent of the cases were of battle origin. Three-fourths of the remaining cases originated in disease and the other quarter in nonbattle injuries. Nearly 90 percent of the empyemas secondary to battle in-

TABLE 14.—*Distribution of a 20 percent sample*[1] *of secondary cases of empyema of the chest in the U.S. Army, 1944,*[2] *by area of admission, type of admission of primary condition, and evacuee status*

[Preliminary data based on tabulations of individual medical records]

Type of admission	Continental United States	Overseas						
		Europe	Mediterranean	Middle East	China-Burma-India	Southwest Pacific	Central and South Pacific	North America
	EVACUATED							
Battle injury and wound:								
Thoracic	------	36	8	------	1	4	1	------
Thoracoabdominal	------	5	8	------	------	------	------	------
Other regions	------	8	1	------	------	------	------	------
Total	------	49	17	------	1	4	1	------
Nonbattle injury:								
Thoracic	------	1	------	------	------	------	------	------
Thoracoabdominal	------	1	------	------	------	------	------	------
Other regions	------	1	------	------	------	------	------	------
Total	------	3	------	------	------	------	------	------
Disease:								
Pneumonia	------	1	------	------	------	------	------	------
Bronchiectasis	------	1	------	------	1	------	------	------
Other diseases	------	5	1	------	------	1	1	1
Total	------	7	1	------	1	1	1	1
Grand total	------	59	18	------	2	5	2	1

See footnotes at end of table.

[1] It should be pointed out again that the term "admissions" refers to patients admitted to medical treatment facilities for the specified condition as the primary cause of admission, while the term "incidence" includes not only these patients but also patients in whom the specified condition was reported as secondary to other admission diagnoses.

TABLE 14.—*Distribution of a 20 percent sample* [1] *of secondary cases of empyema of the chest in the U.S. Army, 1944,* [2] *by area of admission, type of admission of primary condition, and evacuee status*—Continued

[Preliminary data based on tabulations of individual medical records]

Type of admission	Continental United States	Overseas: Europe	Overseas: Mediterranean	Overseas: Middle East	Overseas: China-Burma-India	Overseas: Southwest Pacific	Overseas: Central and South Pacific	Overseas: North America
	NOT EVACUATED							
Battle injury and wound:								
Thoracic	------	1	------	------	------	1	------	------
Thoracoabdominal	------	------	1	------	------	------	------	------
Other regions	------	------	------	------	------	------	------	------
Total	------	1	1	------	------	1	------	------
Nonbattle injury:								
Thoracic	4	------	------	------	------	1	------	------
Thoracoabdominal	------	------	------	------	------	------	------	------
Other regions	1	1	------	------	1	1	------	------
Total	5	1	------	------	1	2	------	------
Disease:								
Pneumonia	26	3	4	2	------	------	------	------
Bronchiectasis	2	------	------	------	------	------	------	------
Other diseases	21	------	2	------	------	------	------	------
Total	49	3	6	2	------	------	------	------
Grand total	54	5	7	2	1	3	------	------

[1] Two sample cases—one admission each in the European theater and in the Southwest Pacific Area—have been omitted from the table since they could not be located in the card file.

[2] 1944 refers to year in which primary cause of admission occurred. The empyema may have occurred in that year or subsequent to 1944.

jury followed injuries of the chest or thoracoabdominal region. There were 115 separations from service for empyema during the 1942–45 period.

PATHOGENESIS OF ORGANIZING HEMOTHORAX

Natural History of Simple Hemothorax

Origin of blood.—Though it was not always possible to determine the exact origin of the blood in the pleural cavity, by far the most frequent source was wounds of the lung. Hemorrhage from the lung, however, tends to spontaneous arrest within a short time. Lacerations of intercostal vessels were the

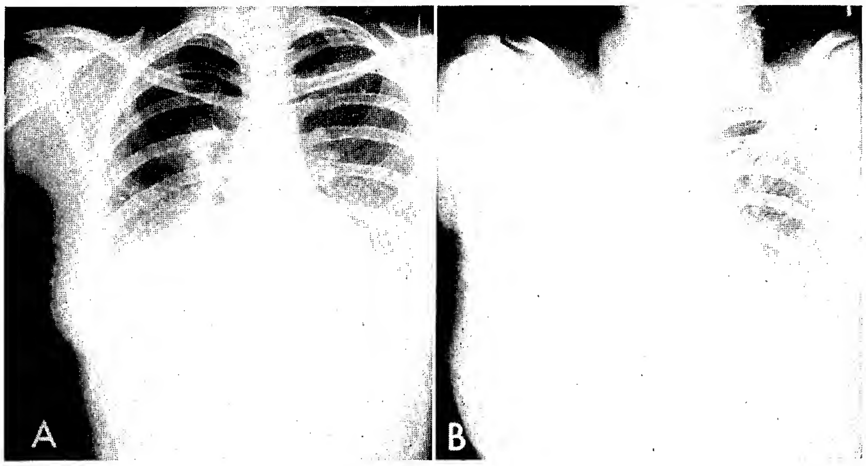

FIGURE 71.—Hemothorax with recurrent pulmonary hemorrhage. A. Postero-anterior roentgenogram showing extensive right hemothorax, with retained foreign body, 7 days after wounding. B. Same, 7 days later, after secondary hemorrhage from lung.

second most frequent source; in many instances, bleeding from these injuries was combined with bleeding from wounds of the lung. In a much smaller number of injuries, the source of the bleeding was the internal mammary vessels; the vessels of the heart, the pericardium, or both; and the larger vessels, such as the innominate and subclavian arteries and the azygos vein. As has already been pointed out, casualties with injuries of the great vessels of the chest seldom survived to reach a field hospital.

Secondary hemorrhage into the pleural cavity was extremely uncommon. It was recorded only 3 times in 752 cases of hemothorax studied by Major Burford and Major Parker. In only one of the three cases did the hemorrhage recur from the lung (fig. 71), 2 weeks after wounding. In the second case, the recurrence was from a laceration of the intercostal artery. In the third case, an unsuspected traumatic aneurysm of the right subclavian artery ruptured, and the patient died almost at once (p. 45). The roentgenologic examination (fig. 72) did not arouse the suspicion that a lesion of such potential gravity could coexist with the characteristic picture of clotted hemothorax.

Effects of blood on pleural structures.—In spite of the problem hemothorax has presented, at least in combat wounds, there have been remarkably few studies of the intrapleural changes associated with it. The fluoroscopic studies made by Edwards and Davies (*4*) in 1940 represent one of the first serious efforts to ascertain the nature of the pleural response to blood in the pleural cavity. Before the war, opinions differed concerning its irritative effects. The World War II experience was not conclusive, and final judgment must be reserved.

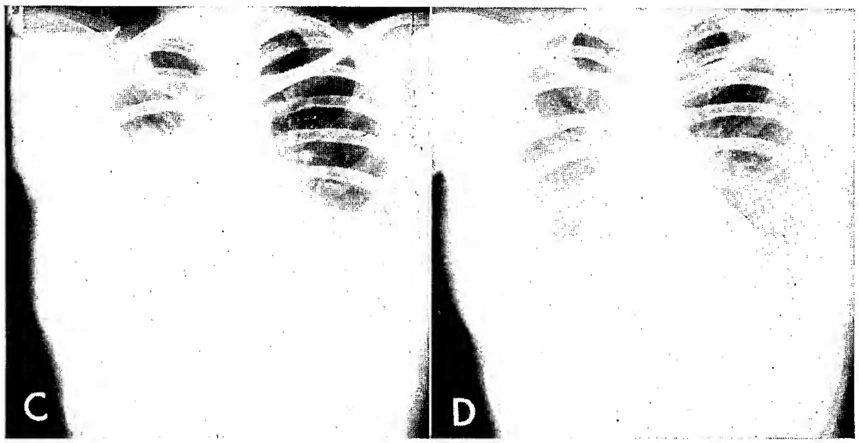

FIGURE 71.—Continued. C. Same, 2 days later, showing residual clotted hemothorax after two thoracenteses. D. Same, after thoracotomy for removal of foreign body and decortication of right lung. At operation, it was found that the secondary hemorrhage had occurred from a laceration of the lung at site of entry of missile.

Little evidence was produced in World War II to substantiate the theory that unaltered liquid blood acted as an inflammatory agent. This generalization held, however, only while the blood remained unaltered. There seemed no doubt that it underwent rather profound physiochemical changes as soon as it left its normal endothelial-lined habitat and that these changes were progressive in both kind and degree. The first fluid aspirated after wounding was pure blood or distinctly bloody, but its character changed as aspirations were continued. It became serosanguineous, and then, before the chest was entirely emptied, it became merely serous.

A fibrin layer was uniformly found on the pleural surface in all hemothoraces. It was always more pronounced in clotted than in unclotted cases. Since clotted blood not only binds fibrin but also represents a greater physiochemical departure from normal than a liquid hemothorax, in which fibrin is free, the inference was that the fibrin layer represented an inflammatory response rather than a passive deposition of fibrin or a salting-out phenomenon. As would be expected, the response was proportional to the degree of alteration of the blood; that is, whether it was (1) clotted or (2) clotted and contaminated.

In the hemothoraces controlled by thoracenteses, laboratory studies showed that the pleural fluid was low in protein and relatively free of red blood cells. Even in uncomplicated hemothoraces, as just pointed out, a certain amount of fibrin was deposited over the pleural surfaces, but the thin, shaggy coat was not demonstrable on roentgenologic examination, and the fibrin content of the intrapleural fluid was so small that total aspiration was entirely feasible (fig. 73).

FIGURE 72.—Posteroanterior roentgenogram showing clotted right hemothorax. There is nothing in the film to suggest the traumatic aneurysm of the first portion of right subclavian artery, rupture of which was immediately fatal.

Theories of Origin of Organizing Hemothorax

The pathogenesis of organizing hemothorax was no clearer at the end of the war than at the beginning. There were no facilities in a combat zone for experimental studies on why clotting occurred in some traumatic hemothoraces and did not occur in others. Clinical and pathologic observations in a large number of chest injuries do, however, permit a certain amount of legitimate speculation.

Certain causes could be eliminated at once. An analysis of the missiles that caused the wounds associated with clotted hemothorax revealed no common denominator to explain what occurred. The degree of pneumothorax present apparently played no part, as might have been expected; the presence or absence of air does not influence the clotting of blood. The relative severity of the wounds of the lungs and soft tissues played no decisive role; hemothorax was more frequent in severe injuries because severe injuries were more frequent. Organizing hemothorax occurred in some cases in which the injury was limited to the external chest wall and also occurred in some contusions and blast injuries.

With these obvious factors eliminated, it was necessary to turn to the mechanism of clotting for a possible explanation of clotted or organizing hemothorax. There were three theories:

1. The first hypothesis was that bacteria might be present in the pleural cavity and, in the presence of blood, might incite an exudative response, which

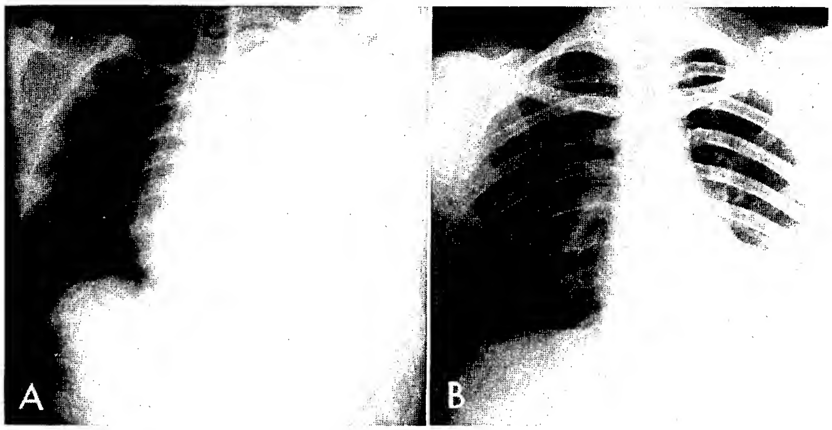

FIGURE 73.—Massive liquid hemothorax without infection. A. Postero-anterior roentgenogram made shortly after wounding and showing hemothorax. B. Same, 10 days later, after six thoracenteses, by which a total of 3,150 cc. of blood and other fluid was removed.

would favor the formation of fibrin deposits, rather than a transexudative response. If bacteria were seeded generously over the pleural surfaces, a frankly suppurative response would be expected, and a true suppurative pleuritis would develop. If, however, they were implanted in such small numbers as not to incite a widespread pleural response, their presence might still be sufficient to alter the response from transexudative to exudative, and the clinical picture would be dominated by the presence of fibrin deposits rather than by suppuration.

The sharp and often prolonged febrile responses seen in organizing hemothorax furnished clinical evidence of the exudative character of the pleural response to blood. In uninfected hemothoraces, a moderate febrile response often occurred, but it was practically always of short duration, usually no longer than from 10 to 14 days. In infected cases, the clinical manifestations continued, and if suppuration were impending, they became more pronounced.

Bacterial seeding probably explained some instances of organizing hemothorax, but it could not be accepted as a universal explanation. It was undoubtedly a factor in some hemothoraces which went on to empyema. The fact that nonhemolytic *Staphylococcus aureus* was the most frequent causative organism in empyema and that this organism does not produce fibrolysin lent some support to this theory. Clotted blood containing pathogenic bacteria served as an excellent culture medium, just as devitalized muscle served as a culture medium in all wounds. This was particularly true of anaerobes, which develop rapidly under low oxygen tension. Clot formation about bacteria in hemothorax also had the effect of preventing penicillin or the sulfonamides from reaching these entrenched organisms. They were not influenced by either local or systemic therapy.

2. The second hypothesis was that clotting in hemothorax might be the result of the simultaneous presence of blood and coagulative ferments in the pleural cavity. This theory was not considered acceptable. For one thing, the actual amount of blood present seemed of no importance; the preponderance of white clot present in some cases pointed to an excess of plasma. There was also no uniformity in the time at which clotting occurred. Clotted blood was sometimes found in the pleural cavity when thoracotomy was performed from 4 to 6 hours after wounding. Sometimes, the clot was so firm a few days after wounding that it defied needle aspiration. In other instances, the blood might remain liquid for many days, and all of it could be removed by thoracentesis.

There was no acceptable explanation for these variables. It might be that the churning movements of the diaphragm, heart, lungs, and chest wall had a defibrinating effect. Sellors (*5*) remarked that any surgeon who opened a recent hemothorax must have been impressed "by the tumultuous way in which the blood is flung about the pleural cavity." Fibrin and blood clots were often seen in the costophrenic sinus and the lower portion of the pleural cavity within a short time after wounding. Another consideration was that both the lungs and the muscles are ready sources of thromboplastin.

Even granting all of these facts, acceptance of the theory that the presence of whole blood and coagulative ferments was responsible for organizing hemothorax would leave many cases unexplained.

3. The most reasonable hypothesis was that, as the result of trauma, normal pleural fluid was so modified that it became exudative rather than serous. As has already been pointed out, a response by the pleura could be expected whenever blood was spilled into the pleural cavity as the result of wounding, even if the process went no further. Moreover, wounds of the lungs and pleura cannot be fundamentally different from wounds of other tissues. If this reasoning is sound, the so-called edema of wounding might be expected to occur in these tissues just as in other damaged tissues. The presence of edema, which reached its peak within 2 to 4 days after wounding, could reasonably be assumed to affect the character of the pleural effusion caused by trauma, in all probability making it richer in fibrin. There would then be present in the pleural cavity an excess of coagulative ferments from the wounded chest wall or lung or both, combined with an excessive fibrin from the pleural effusion. In other words, there would be added to the whole blood spilled into the pleural cavity, which might itself clot by natural physiologic processes, increments from the pleural response to wounding that would enhance the natural process of clotting.

It is easy to explain why early thoracotomy and evacuation of whatever intrapleural fluid was then present did not necessarily protect the patient against the development of a subsequent clotted intrapleural mass. Wounds of the thorax frequently resulted in the widespread changes known as wet

lung (p. 207). Wet lungs were heavy and soggy, and they expanded only sluggishly and never completely in the absence of vigorous corrective measures. For a few days after wounding, therefore, dead space [2] in the pleural cavity permitted the accumulation of pleural exudate that eventually became a part of, or constituted, the clotted intrapleural mass. If all the blood in the pleural cavity had been evacuated at thoracotomy or otherwise, the pleural exudate that continued to accumulate under these circumstances was chiefly white. If all the blood had not been removed, the clot would be layered or marbled.

The hypothesis seems reasonable that a change in the character of the normal pleural fluid furnishes an explanation for the clinical vagaries observed in clotted hemothorax. It also seems to explain the sequential relation of this process to the original trauma.

PATHOLOGIC CHANGES IN CHRONIC TRAUMATIC HEMOTHORAX

The limited pathologic studies possible in a combat zone seldom warrant generalizations on any subject. A large enough number of hemothoraces were observed, however, to elucidate the pathologic changes in chronic traumatic hemothorax and to establish the rationale for its management.

Gross Pathology

All hemothoraces, as already pointed out, involved typical and definite changes within the pleural cavity, slight at first but more pronounced as the process went on to clotting and organization.

The process of hemo-organization began with the laying down of a thin, loosely adherent film of fibrin and blood cells over both pleural surfaces. Within 2 or 3 days of its formation, angioblastic and fibroblastic proliferation began to occur.[3] As early as from 7 to 14 days after wounding (figs. 74 and 75), fibroblasts could be seen growing out from the older (pleural) side toward the younger portion. The transition to adult fibrous tissue was progressive and rapid (fig. 76). Capillaries grew in from the pleura, and within 8 to 10 weeks, complete cellular symphysis had occurred in most cases. Decortication, which would have been simple earlier, had now often become impossible (figs. 77 and 78).

[2] Dead space may be defined as any air or fluid or matter without the confines of a normal anatomic habitat and without a blood supply.

[3] These observations were made on specimens secured at operation for bronchopleural fistulas, removal of foreign bodies, and similar conditions. Small clotted hemothoraces were often found at these procedures, and, when interest in this complication of thoracic wounds had developed, sections were regularly taken for study.

FIGURE 74.—Photomicrograph showing organizing hemothorax with replacement of acute fibrinopurulent deposit by young vascular connective tissue at end of first week after wounding. The pleural aspect of the layer of exudate removed from the visceral pleura is toward left and periphery toward right.

The essential feature of chronic traumatic hemothorax was the formation of this fibroblastic and fibrinofibrous membrane or peel over the visceral and parietal pleurae. Once it had formed, the hemothorax was converted into an enclosed hematoma of the pleural space (fig. 79).

It should be emphasized that, in the beginning, the pleura itself took no part in the pathologic process. Until fusion between it and the rind occurred, it remained remarkably normal in appearance. The pleural thickening which was sometimes described on roentgenograms was never observed at operation. The practice of describing peripheral obscuration as thickened pleura was incorrect and misleading. In the early phases of an organizing hemothorax, examination of sections of the encasing sac never revealed elastic tissue, although elastic fibers were always found in sections from the lung or the soft

FIGURE 75.—Photomicrograph showing fibroblastic membrane from clotted hemothorax 11 days after wounding. Note that, even at this early stage, the hemothorax has a definite capsulelike character. Capillaries have already begun to appear in older (pleural) side at bottom of specimen. Hematoxylin and eosin stain. (× 60)

tissue of the thoracic wall just beneath the pleural mesothelium. If, however, the process went on without interruption, the membrane eventually underwent complete fibrous and vascular union with the pleura, which then lost its identity as a delimiting membrane.

The facts just stated were of great importance in the selection of the time for decortication (p. 286). The ease with which a cleavage plane could be established between the two layers (the rind and the pleura) at operation was a direct function of the age of the limiting membrane (fig. 78). Experience showed that after 4 weeks from the date of injury the chances of performing satisfactory decortication dropped rapidly with each succeeding week.

The development of infection, even if it went on to suppuration, did not accelerate the process of organization of the hemothorax to any appreciable degree. There was also no evidence that the union between the peel and the underlying pleura was any firmer when infection was present.

The most prominent feature of the intrapleural mass was that it was always relatively or absolutely solid, because of the fibrin component. It was usually thickest in the basal thoracic gutter posteriorly. The distribution of

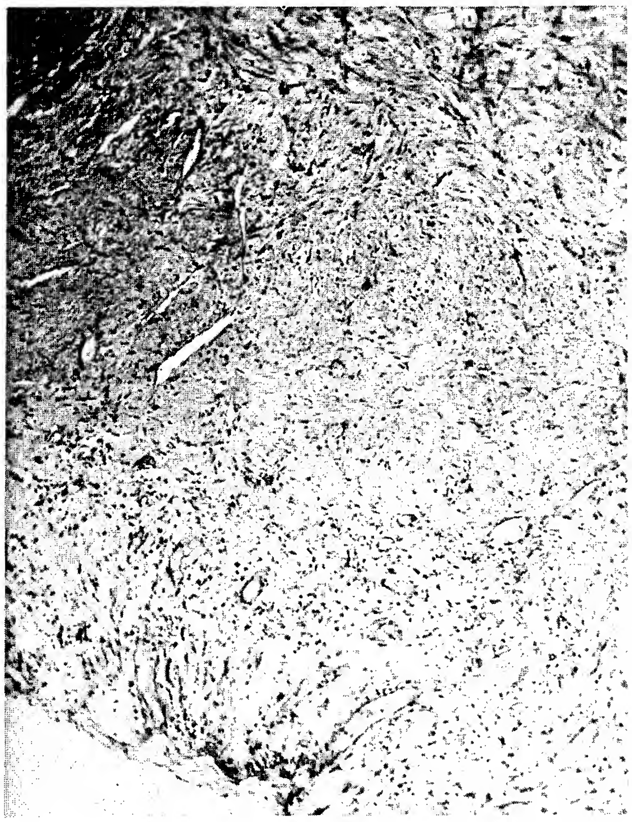

FIGURE 76.—Photomicrograph showing section of peel of clotted hemothorax 4 weeks after wounding. Membrane has assumed a definitely fibrous character. Capillaries are visible at their point of entrance from visceral pleura (lower left of section). Hematoxylin and eosin stain. (× 100)

the fibrin thus followed the natural principles of gravity as they would operate in any recumbent subject with an accumulation of fluid in the pleura.

In the typical organizing hemothorax, the mass was made up of three layers (fig. 79):

1. The outer layer was a tough organized membrane (rind, peel), the thickness of which was related to the length of time that had elapsed since wounding. At the end of 4 or 5 weeks, the rind was usually from 2 to 4 mm. thick. Later, it might be from 5 to 8 mm. thick, or even thicker. If the mass was composed of solid fibrin, the rind was always very thick.

This rind completely surrounded the original hemothorax and was intimately attached to the visceral and parietal surfaces of the pleura, though usually, in spite of the intimacy of the adhesions, it could be separated without difficulty from the visceral pleura, at least in early stages of the process. The

FIGURE 77.—Photomicrograph showing section from clotting hemothorax. Note fusion between dense layer of collagenous connective tissue and subjacent pleura and lung (lung is to left).

rind was resistant, did not tear readily, and had the gross appearance of fibrous tissue.

The rind usually passed directly from the visceral to the parietal pleura at all points at which these surfaces met, but attenuated projections frequently extended beyond these limits, along opposed pleural surfaces or into the interlobar fissures. The costophrenic gutter was almost consistently obliterated by the elevated diaphragm and was sealed off by the reflection of the peel. Beyond these points of symphysis, it was often surprising to find only a thin layer of filmy pleural adhesions. At a greater distance, entirely free pleural space might be encountered.

2. The middle layer of the chronic traumatic hemothorax was a soft, unorganized mass, with the consistency of fibrin. It differed from patient to patient in gross appearance, chiefly because of differences in color. Sometimes, it was almost white. Sometimes, it was the color of mahogany. Sometimes, it was

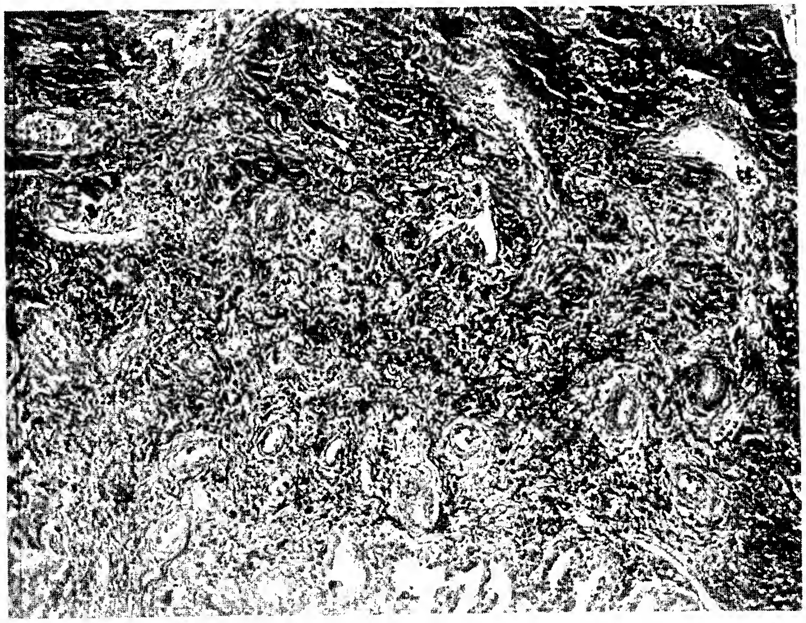

FIGURE 78.—Photomicrograph of section through membrane, pleura, and lung (lung is at lower margin) in posttraumatic empyema 12 weeks after wounding. Note cellular intimacy. No line of demarcation can be seen, and surgically no line of cleavage could be established. This patient's chance for decortication was forfeited by delay in resorting to it. Van Gieson's stain. (× 100)

definitely bloody. A certain amount of marbling was not uncommon, but it was more frequent to find the middle layer the same color throughout. Differences in color seemed to depend upon the relative proportions of blood and plasma in the mass or upon the amount of pleural effusion or pleural exudate that had originally accumulated and that had been modified by whatever degenerative changes might have occurred with the passage of time.

3. The third layer (center) of the intrapleural mass was typically lobulated (fig. 79). It might consist of a single large space or of a network of spaces. Sometimes, it was a mushy core from whose interstices fluid could be squeezed. The fluid looked like what it was, supernatant fluid from a mass of retracting fibrin. It varied in color from yellow to red, brown, or mahogany.

The formation of the central fluid-filled space or spaces was clearly the result of retraction of the original clot. In fact, the whole pathologic process in organizing hemothorax did not seem to differ in any important way from the well-known process of organization in intravascular thrombi.

The foregoing description bears out what has already been said (p. 238), that the term "organizing hemothorax" or "chronic traumatic hemothorax"

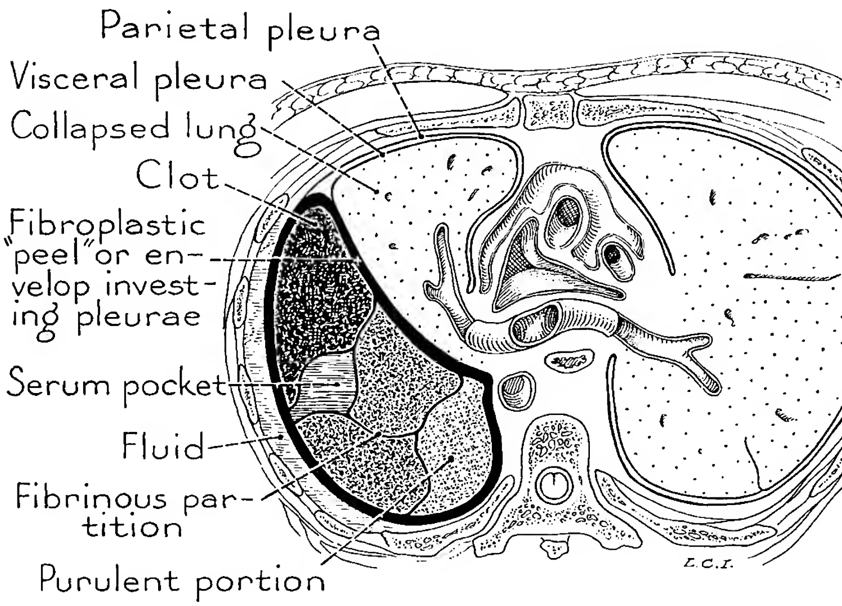

FIGURE 79.—Cross-sectional diagram showing pathologic process in clotting, organizing hemothorax. Membranous peel (rind), essentially a fibrinofibrous envelope, is shown investing visceral and parietal pleurae. In center is loculated purulent material. Loculation explains why in many infected hemothoraces infection could not be diagnosed by thoracentesis, because aspirating needle did not reach center of process, which was recognized only at operation.

carried no implication of the origin or gross appearance of the intrapleural mass. The nomenclature suggests that the mass might be the result of the presence of clotted blood alone, as in some instances it was. The gamut was run, however, from such cases through (1) those in which a considerable portion of blood was still present but in which there were also present increments of white clot (that is, plasma, fibrinous pleural effusion, or fibrinous exudate) to (2) those in which the entire mass seemed to consist of white clot. The variations seemed due not so much to the amount of whole blood originally spilled into the pleura as to the pleural response to its presence.

Histopathology

Histologic examination of sections from an organizing hemothorax confirmed the gross observations (figs. 74–78 and 80–85). As already pointed out, as early as 7 to 10 days after wounding, there was microscopic evidence of fibroblastic and angioblastic proliferation from the pleural surfaces to the clot. The peel or rind thus formed increased progressively in thickness as the fibroblastic invasion continued.

FIGURE 80.—Photomicrograph showing layer of fibrin 3 mm. thick removed from visceral pleura in uninfected clotted hemothorax 11 days after wounding. Note beginning organization in portion immediately adjacent to pleura (on left).

Within 3 or 4 weeks after wounding, adult fibrous tissue was demonstrable in the outer layer of the organizing hemothorax. The fibers and nuclei were arranged roughly parallel to the surface. The long axes of the capillaries were at right angles to the surface, and the capillaries were continuous through the pleura.

Within 4 to 7 weeks after wounding, small arterioles, with smooth muscle fibers in their walls, could be demonstrated at or near the outer surface of the peel. Active fibroplasia continued along the inner (younger) surface, with resulting increases in the thickness of the rind. In some instances, layers of fat cells developed in the peel along the outer surface. It was speculated, but never proved, that this phenomenon might possibly represent a regressive process, heralding eventual degeneration and absorption of the peel. For reasons not clear, the membrane was always thicker, more vascular, and more adherent on the parietal than on the visceral pleura.

FIGURE 81.—Fibrotic process in organizing hemothorax. A. Photomicrograph showing section of fibrofibrinous layer removed from visceral pleura in uninfected clotted hemothorax. Note fibrosis in portion of rind adjacent to pleura at top. B. Photomicrograph showing more pronounced fibrous changes at distal free margin of same section.

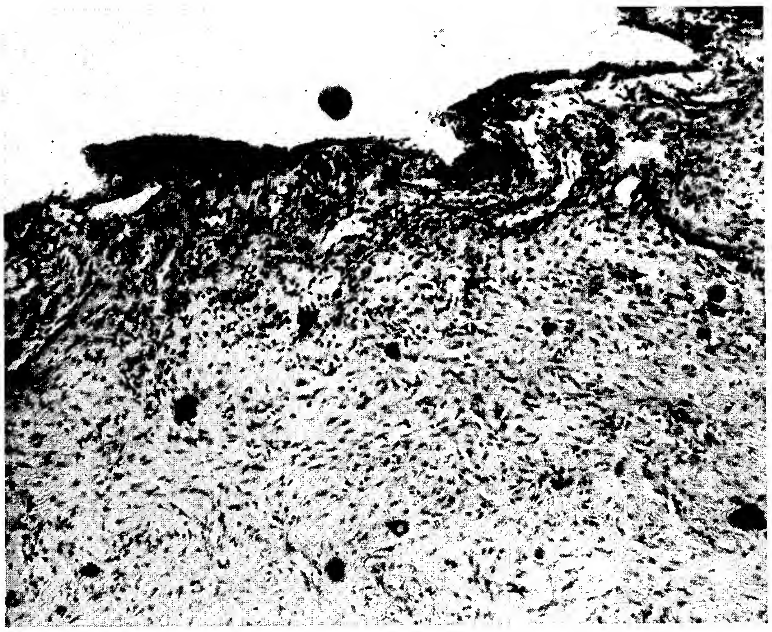

FIGURE 82.—Photomicrograph showing calcium deposition in collagenous connective tissue layer of exudate on visceral pleura in organizing hemothorax.

Microscopically, the rind in hemothoracic empyema could not be differentiated from the rind in organizing hemothorax without infection. The only evidence of inflammation seen under the microscope was observed on the inner surface of the rind, along which fibrin or blood clot was in process of organization. It was limited to infiltration by varying numbers of polymorphonuclear leukocytes (fig. 85).

The second (middle) layer appeared on microscopic examination to be merely a mass of fibrin with scattered, formed blood elements trapped in its meshes.

Pulmonary Effects of Organizing Hemothorax

When the process of organization was complete, a dense fibrous membrane encased some portions of the lung, or the whole lung, thus limiting its mobility and preventing its complete expansion. A contraction of the hemithorax was sometimes present also. Even in the early stages of an organizing hemothorax, it was easy to see that the tough, resistant, inelastic rind that invested the visceral pleura effectively prevented pulmonary reexpansion. If the process were not terminated by surgical measures, fibrosis increased, and the rind and the pleura became intimately adherent. As time passed, tough scar tissue extended through the pleura into the interstitial pulmonary tissue. The degree of cel-

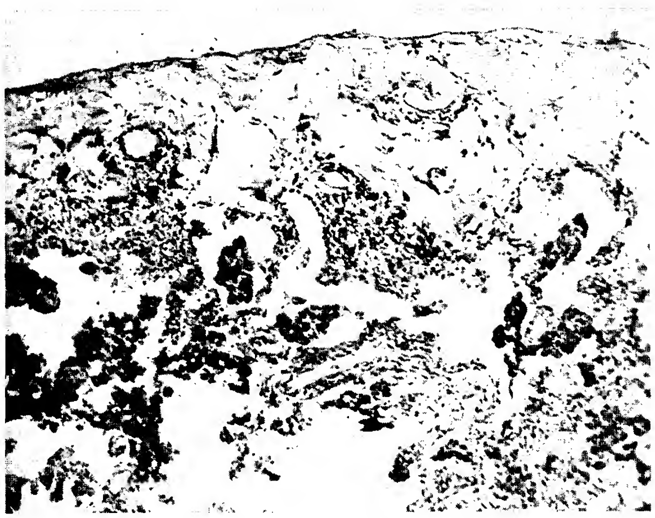

FIGURE 83.—Photomicrograph showing biopsied section of lung and pleura after removal of overlying exudate. Note that pleura retains most of its normal characteristics.

lular intimacy made it difficult, and sometimes impossible, to develop a cleavage plane at operation, particulary if the pleura had been denuded or the lung wounded. In such cases, the results of surgery were not likely to be good: The lung, even when liberated by the procedure of decortication, could not expand because the fibrotic process had extended to it. When complete pulmonary reexpansion was impossible, the stage was set for the development of infection.

When the intrapleural mass was removed, it was frequently evident that the lung had not only been compressed by the intrapleural accumulation but had also been greatly displaced and had sometimes been infolded also (p. 183).

Resolution

Massive organizing hemothorax not treated by surgery could terminate in two ways: (1) by the formation of a fibrothorax or pleural calcification (fig. 82) or (2) by the development of a suppurative process. Spontaneous resorption of small and even moderate amounts of accumulated clotted blood or small amounts of fibrin was conceivable. If resorption of larger amounts occurred, which was not usual, recognizable sequelae were almost inevitable.

The rapidity and extent of clearance in any given hemothorax were impossible to predict. In some cases in which the initial observations gave promise of complete and prompt resolution, the process might suddenly become static, usually about the fourth week. Perhaps the chief reason for the dis-

FIGURE 84.—Photomicrograph showing replacement of fibrinous exudate, pleura, and adjacent lung (lung is at extreme left) by collagenous connective tissue in organizing hemothorax.

cussion concerning the optimum timing of decortication (p. 286), which continued throughout the war, was the lack of agreement concerning the possibilities of resolution in an organizing hemothorax. The exact size and type of an intrapleural mass in which spontaneous resolution might be expected were never agreed upon, nor was the length of time in which expectant treatment should be practiced. Generally speaking, cavities involving less than 50 percent of the pleural space or less than 500 cc. in volume usually cleared spontaneously over a 6-week period, but this was a generalization to which there were multiple exceptions. No doubt, the most important consideration was the thickness of the intrapleural mass. It was repeatedly observed that roentgenologic clearing was confined to the inner portions of the clot. The thickest areas, notably the portion in the posterior thoracic gutter, were still clearly demonstrable on roentgenograms after almost complete clearing of other areas had occurred.

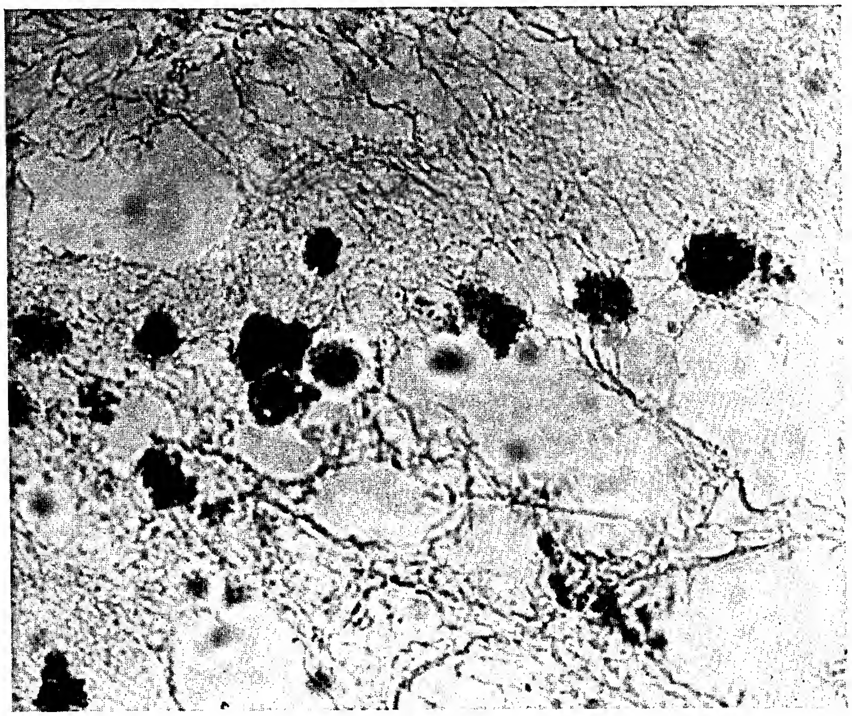

FIGURE 85.—Photomicrograph showing infected organizing hemothorax with bacteria (*Staphylococcus hemolyticus* on culture) deep in unorganized portion of fibrin and growing in masses in its meshes. Note conspicuous absence of leukocytes.

BACTERIOLOGY OF ORGANIZING HEMOTHORAX

Hemothoraces represent the largest hematomas with which the body must deal. They are usually far too large to vascularize rapidly, which probably accounts for their tendency to infection, particularly when they are of the clotted type. This tendency was one of the many reasons why it was important that thoracentesis be performed promptly and repeated as necessary.

All types of bacteria were isolated from hemothoraces, including a surprisingly large proportion of anaerobic streptococci and staphylococci. Bacteriologic findings in 24 cases of hemothoracic empyema are shown in the following tabulation:

Bacteria	*Number of cases*
Proteolytic and saccharolytic clostridia	2
Micrococcus tetragenus	2
Hemolytic *Staphylococcus aureus*	1
Hemolytic *Staphylococcus aureus*, proteolytic *Clostridium*	1

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Bacteria	*Number of cases*
Hemolytic *Staphylococcus aureus,* hemolytic *Streptococcus, Pseudomonas aeruginosa*	1
Hemolytic *Staphylococcus aureus, Escherichia coli, Aerobacter aerogenes,* nonhemolytic *Streptococcus*	1
Streptococcus viridans	1
Hemolytic *Streptococcus*	1
Anaerobic *Streptococcus*	1
Nonhemolytic *Streptococcus, Pseudomonas aeruginosa*	1
Streptococcus viridans, proteolytic and saccharolytic clostridia, *Bacillus proteus*	1
Proteolytic *Clostridium*	1
Escherichia coli	1
Escherichia, type unidentified	1
Clostridium, unclassified	1
Cultures sterile	6
Pseudomonas aeruginosa	1

Clostridial infections, which were not numerous, were nearly always caused by non-gas-forming bacteria. Remarkable combinations of bacteria were found in both the liquid and the unclotted hemothoraces. In the order of frequency, the offending organisms were streptococci, clostridia, staphylococci, *Escherichia*, and *Pesudomonas*. Regardless of the bacteriology, the clinical course was essentially the same, except that when *Escherichia* was present, the illness was usually more serious.

In some cases, bacteriologic confirmation was lacking in spite of clear-cut signs that infection had occurred. There were two explanations:

1. Bacteria might not be present in demonstrable numbers in the fluid portions of the mass.

2. The needle might, by chance, have been introduced into loculations (fig. 79) in which the fluid was still uninfected. If this was the explanation and infection had actually occurred, repeated efforts to find organisms would eventually be successful as the infection spread to the entire mass or as more rewarding sites were selected for aspiration.

In some patients, for whom no explanation was forthcoming, signs of sepsis were clear cut and organisms were found in fluid aspirated from the chest, but there was virtually no leukocytic response (fig. 85). In this group of cases, the fluid was thin and practically without sediment, even when organisms were present in large numbers.

In some cases, suppuration, as evidenced by purulent material on aspiration, did not manifest itself for 4 to 6 weeks. In a considerable number of these cases, it had been thought that resolution was occurring. The factor (or factors) which determined which cases would go on to prompt suppuration and in which suppuration would be delayed or would not be evident at all was never clearly demonstrated. Whatever the factor (factors) might be, the explanation was probably the balance or imbalance between (1) the rapidity and extent of the clotting that trapped the infecting bacteria in the fibrous mass

and kept them from contact with the pleura and (2) the ability of the pleura to control or eliminate the bacteria that were originally in contact with it. If the organisms in an infected hemothorax were virulent and if seeding was heavy and early, a suppurative pleuritis was likely to occur promptly. Both the liquid and the clotted contents of the intrapleural space would be involved in the pathologic process. If, however, for one reason or another, the contaminating bacteria did not gain the ascendancy and instead became entrapped within the clotted intrapleural mass, then the mechanism of a delayed or latent infection was set up.

PHYSIOPATHOLOGY OF HEMOTHORAX

The bony thorax imposes definite limitations on the size of the thoracic cavity. This means that any space-occupying medium can seriously disrupt the normal function of the heart and the lungs. From this point of view, pneumothorax and hemothorax produced almost identical physiopathologic results. By impeding cardiac return and pulmonary expansion, they tended not only to reduce the volume of circulating blood but also to decrease the degree of oxygen saturation. The response was an increased cardiac and respiratory rate, both of which were almost invariably observed in any severe thoracic injury. The pain caused by damage to the thoracic cage and the voluntary restriction of motion to minimize the discomfort further added to the physiologic disturbances because the respiration was rapid and shallow and the pulse was fast. For these various reasons, it was necessary to empty the chest of blood and air as rapidly as possible.

CLINICAL PICTURE AND DIAGNOSIS

Simple hemothorax.—The diagnosis of simple hemothorax almost never offered any difficulty. The history of wounding was clear cut. Hemothorax was known to be the most frequent complication of thoracic wounds. Finally, the pleural contents were readily aspirable. At first, the fluid was blood or bloody. Later, if resolution began to occur, the blood disappeared and the fluid became serous, as well as scantier, on successive aspirations.

Roentgenologic examination revealed intrapleural obscuration consistent with the presence of fluid (fig. 86). The lung margin was characteristically distinct and scalloped. This finding was particularly suggestive if the lateral view revealed the process localized to the posterior half of the involved hemithorax.

Organizing hemothorax.—The diagnosis of organizing hemothorax was not always so simple. In the early stages, when clotting had occurred but fluid could still be obtained, it was sometimes impossible to distinguish the condition from a simple hemothorax. Later, it might be necessary to insert

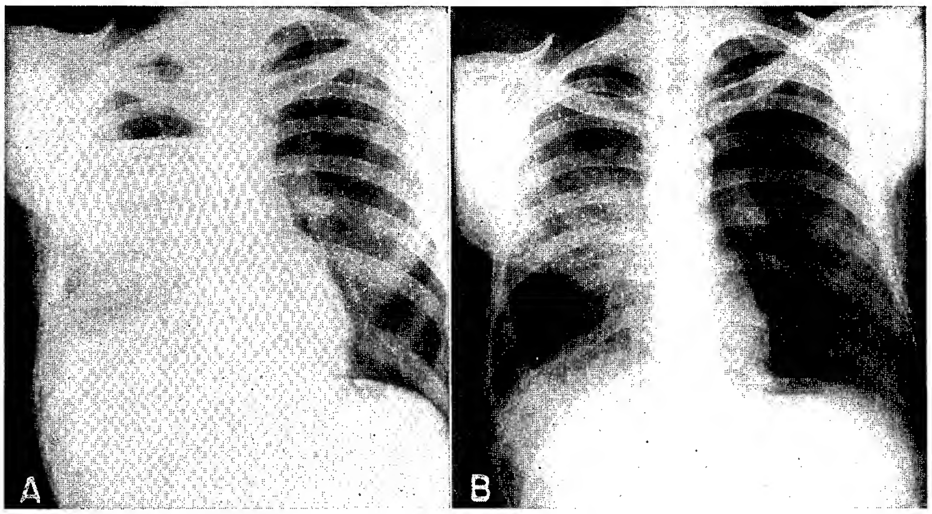

FIGURE 86.—Spontaneous resolution of clotted hemothorax. A. Posteroanterior roentgenogram showing clotted hemothorax on right. B. Same, showing spontaneous resolution after 6 weeks.

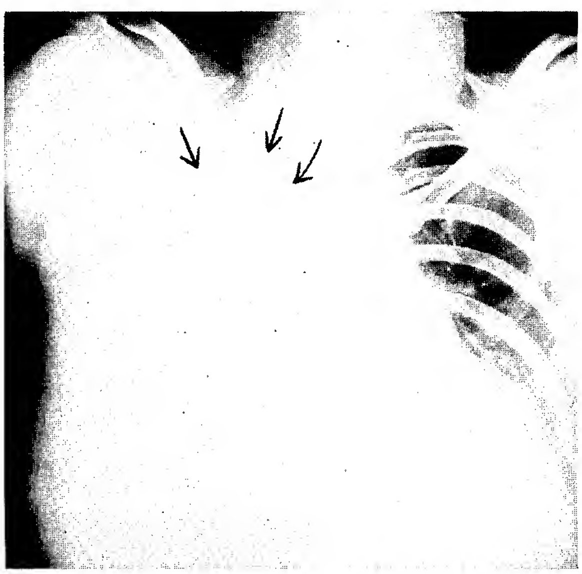

FIGURE 87.—Posteroanterior roentgenogram showing right clotted hemothorax. Note that border of partially collapsed lung is still fairly distinct. In liquid hemothoraces, borders of collection of blood were usually seen only as diffuse haze.

FIGURE 88.—Lateral roentgenogram showing clotted hemothorax over right lower and middle lobes. The sharp superior border seen in this view and not seen in posteroanterior roentgenograms came to be recognized as typical of clotted hemothorax.

the needle into many different areas of the chest to obtain any fluid. The aspirated material consisted of only small amounts of serum, which contained fragments of clot and fibrin threads. Efforts at drainage by insertion of an intercostal water-seal catheter were practically always unsuccessful.

If organization had gone on to fibrosis, the clinical picture was distinctive. A patient with fibrothorax was likely to show an overall contracture of the affected hemithorax; narrowing of the intercostal spaces; elevation and more or less immobility of the leaf of the diaphragm on the affected side; often considerable limitation of movement of the chest wall; and, not infrequently, an associated atrophy of the extracostal musculature, no doubt as the result of disuse.

Roentgenologic examination in organizing hemothorax (figs. 87 and 88) revealed a dense opacity corresponding to the area of the original hemothorax. Resorption and consequent improvement in the roentgenologic appearance (figs. 89 and 90) was observed in a few cases that had reached this stage, but, as a rule, narrowing of the interspaces, as well as contracture and relative immobility of the chest wall, was likely to remain unaltered.

Hemothoracic empyema.—The clinical picture of hemothoracic empyema was that of typical empyema modified by the special considerations introduced

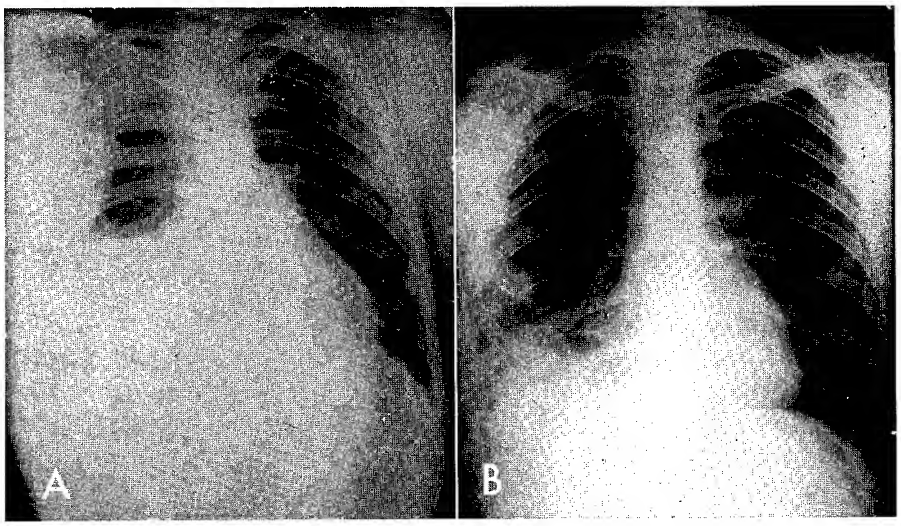

FIGURE 89.—Clotted hemothorax with spontaneous clearing. A. Posteroanterior roentgenogram showing clotted hemothorax 2 weeks after wounding. B. Same, 1 month later. Chest has almost completely cleared by natural processes. Neither thoracentesis nor surgery was used.

by the chest wound. Fever was usually high, and the patient was likely to become more toxic than he had been. There might be an associated pneumonitis with productive cough.

The sudden spillage of purulent pleural fluids in large amounts into the bronchial tree made the diagnosis of empyema with bronchopleural fistula simple. If there was leakage of only a small amount, the diagnosis was more difficult. The finding of a fluid level, otherwise unexplained, on the roentgenogram was almost certain evidence of a fistula.

The diagnosis of empyema was confirmed by the aspiration of fluid that was chocolate brown, foul smelling, or frankly purulent. In some cases, as just noted (p. 262), infection had been present for some time before purulent fluid appeared.

The degree of mediastinal immobility present in any given case depended upon the degree of organization that had occurred in the preexisting hemothorax. It was therefore roughly proportional to the length of time that had elapsed since injury rather than to the duration of the infection or the thickness of the purulent exudate.

Differential diagnosis.—Large extracostal or intrapulmonary hematomas, as well as lobular or lobar atelectasis following bronchial obstruction, were usually readily distinguished from chronic traumatic hemothorax. Pneumonia was also readily distinguished. Infolded lung sometimes offered special difficulties (p. 183).

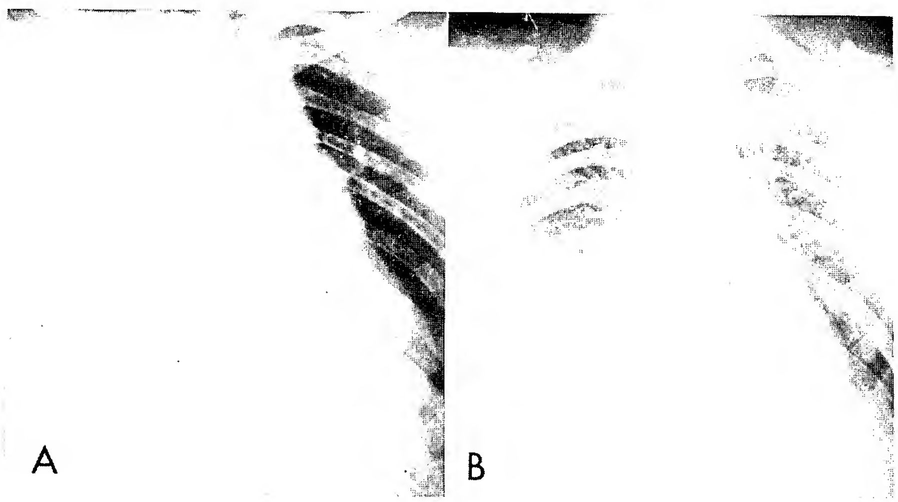

FIGURE 90.—Clotted hemothorax with spontaneous clearing. A. Posteroanterior roentgenogram showing right-sided massive clotted hemothorax, without infection, 2 days after wounding. B. Same, 3 weeks later. Complete spontaneous clearing occurred later in this case, in which evidences of resorption of fluid were noted from beginning.

MANAGEMENT OF SIMPLE HEMOTHORAX

Rationale of Thoracentesis

Thoracentesis was part of the routine of resuscitation for four reasons, all concerned with the restoration of normal cardiorespiratory physiology:

1. To relieve high intrapleural pressure.
2. To permit increased aeration of the pulmonary parenchyma and thus encourage prompt reexpansion of the lung.
3. To correct shock by relieving the hypoxia that was helping to cause it.
4. To relieve the shift of the heart and mediastinum and thus both improve the venous return to the heart and increase the volume flow of blood (fig. 91).

There were three additional reasons for continuing thoracentesis after resuscitation as part of the management of simple hemothorax in forward hospitals:

1. To decrease the possibility of later clotting.
2. To encourage apposition of the lung and the thoracic wall and thus limit the extent of infection if hemothoracic empyema should develop.
3. To prevent late fixation and contraction of the chest.

Failure to carry out aspiration of a simple hemothorax in forward hospitals often presented surgeons working in rear areas with complicated problems of organizing hemothorax and hemothoracic empyema, problems which could be solved only by radical surgery. The management of empyema was the responsi-

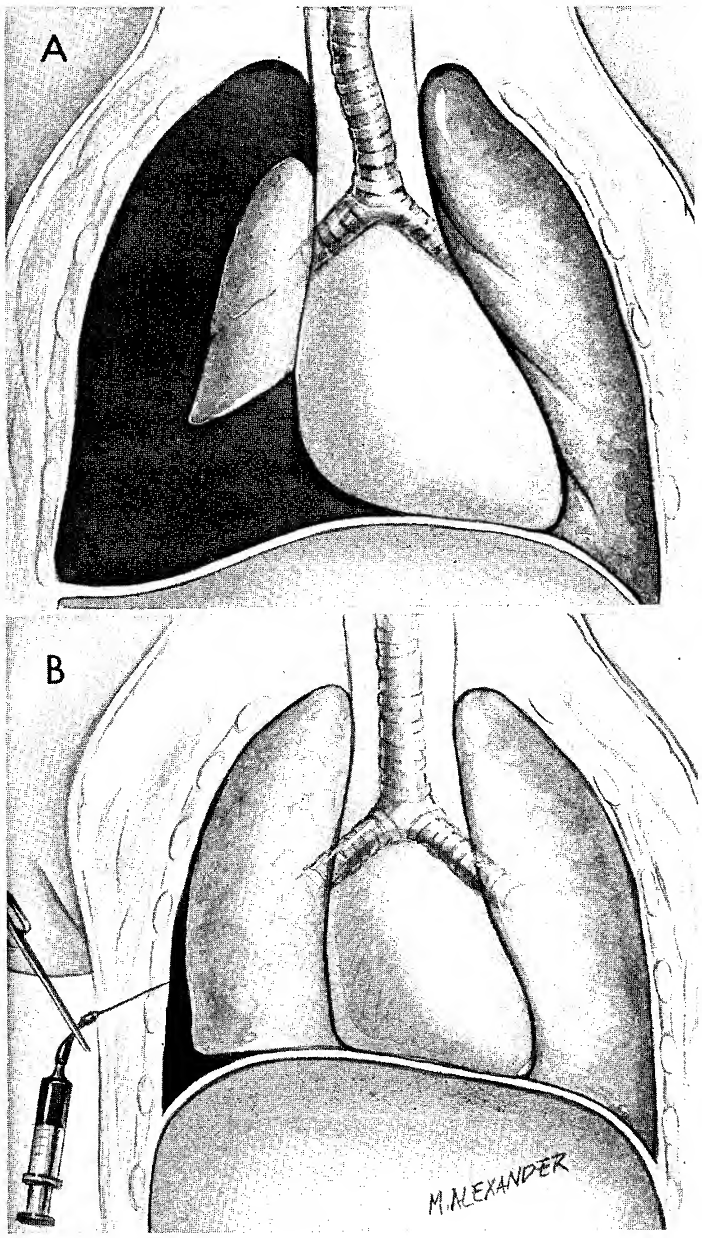

FIGURE 91.—Management of hemothorax by thoracentesis. A. Schematic showing of massive hemothorax with collapse of involved lung and shift of mediastinum with partial collapse of uninvolved lung. B. Expansion of involved lung after removal of blood by simple aspiration of chest. This procedure, in addition to greatly increasing vital capacity, also indicates amount of intrapleural hemorrhage.

bility of surgeons in base hospitals and hospital centers, but its prevention was usually the responsibility of surgeons in forward hospitals.

Very early in the war, the practice of air replacement after thoracentesis was condemned, and all the attention was devoted to the policy of early, vigorous aspiration. Certain objections to thoracentesis that had been advanced before the war proved entirely theoretical:

1. The military experience showed that there was no risk of causing renewed bleeding by thoracentesis; no case is on record in which this happened. This might have been expected. The two chief sources of hemorrhage in chest wounds were extrapulmonary (from the chest wall or the mediastinum) and pulmonary. The existence of a hemothorax, however, had no effect on extrapulmonary bleeding, while the reason that pulmonary bleeding usually ceased spontaneously was not the effect of the hemothorax but the lowered pressure in the pulmonary artery and its branches (p. 153). Many more errors were made in World War II by not aspirating the chest than by aspirating it and taking the remote and theoretical risk of recurrent hemorrhage.

Only one case is on record in the Mediterranean theater in which there seemed to be any connection at all between aspiration of a hemothorax and secondary hemorrhage, and, in this case, the relation was entirely on a post-hoc-ergo-propter-hoc basis. Intrapleural bleeding occurred 10 days after closure of a sucking wound of the chest, after 2,850 cc. of bloody fluid had been aspirated over a 3-day period. Just as preparations were being made for exploratory thoracotomy to determine the source of the bleeding, the hemorrhage ceased as abruptly as it had begun, and recovery thereafter was entirely uneventful.

2. The risk of infection after a properly performed thoracentesis proved negligible.

3. The concept that only small amounts of fluid could be removed at one time proved completely false. Withdrawal of 1,000 to 1,500 cc. at one sitting usually caused no symptoms but, instead, produced relief of symptoms. Occasional patients complained of a tight feeling, pain in the chest, dyspnea, or dizziness after large amounts had been withdrawn, but these symptoms disappeared as soon as aspiration was discontinued and seldom recurred when the procedure was resumed 24 hours later.

If hemorrhage continued or recurred (fig. 92), thoracotomy was indicated. Reaccumulation of 1,000 to 1,500 cc. of blood within a short period after the first aspiration of the chest was likely to be associated with failure to maintain a satisfactory blood pressure and with a falling hematocrit. In these circumstances, simple aspiration could not be expected to be effective.

Technique of Thoracentesis

Since the purpose of the first aspirations of the chest was to relieve pressure and to aid in the restoration of normal cardiorespiratory physiology, it was not necessary to empty the chest completely. At the end of 48 or 72 hours,

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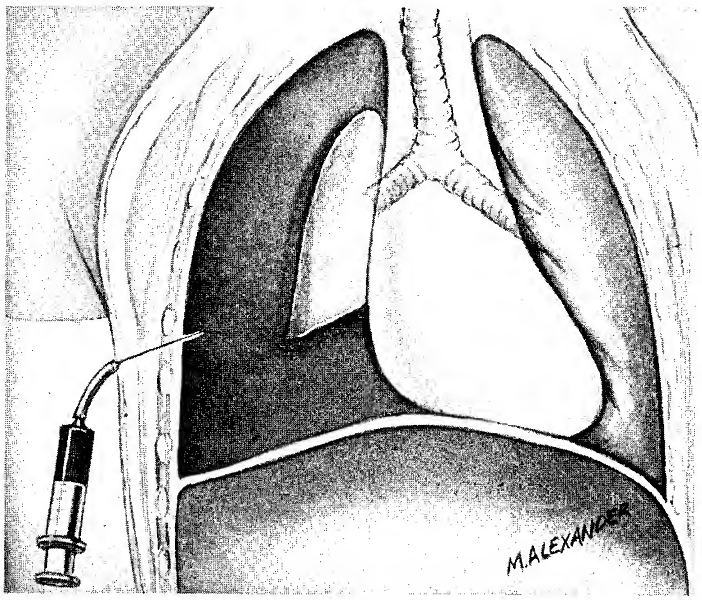

FIGURE 92.—Schematic showing of recurrent hemothorax after thoracentesis.

aspiration was carried out at least once daily, in order to empty the pleural cavity as rapidly and as completely as possible. If thoracentesis had been instituted as soon as the casualty was seen, not more than three to five daily aspirations were usually necessary.

The patient was transferred to the base as soon as he was fever free and the chest had been completely or almost completely emptied. If he was received in a fixed hospital with clinical or roentgenologic signs of fluid, aspiration was resumed and was continued until the chest was empty or until it was clear that other measures would be necessary.

A single negative aspiration was not accepted as conclusive. Often three or four punctures had to be made before a loculated pocket was found. If several punctures produced no results, another surgeon attempted aspiration the next day. The effort was not abandoned in any case in which there was roentgenologic evidence of fluid or a suggestive pleural shadow until repeated attempts to locate and remove the fluid had been made. The fact that blood had clotted (fig. 93) did not necessarily interfere with its aspiration.

Results of Thoracentesis

The results of early, vigorous thoracentesis in hemothorax were excellent from the beginning. If this was the chief or the only complication of a thoracic wound, the great majority of casualties who were treated by this method could be returned to duty within 6 to 8 weeks after wounding.

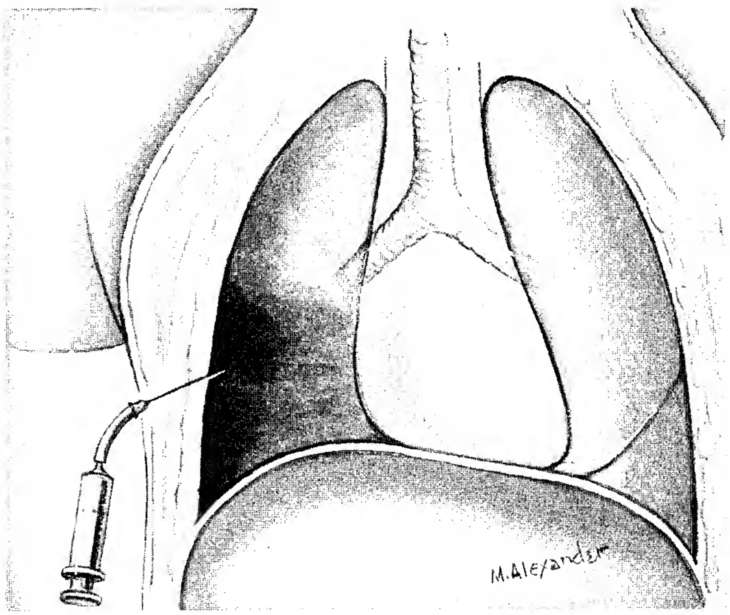

FIGURE 93.—Schematic showing of massive clotted hemothorax. Aspiration of blood is still possible when process of organization is still incomplete, but when physical signs and roentgenologic findings point to a large accumulation of intrapleural fluid and only small amounts of blood can be aspirated, further attempts at evacuating chest are unlikely to be successful. If patient is dyspneic or shows signs of early infection, thoracotomy and evacuation of clots must be undertaken promptly. Usually, however, it is safe to wait for surgery (decortication) at the base.

Results improved as time passed. In August 1943, it was estimated that about 6 percent of casualties with uninfected hemothorax observed at the chest center at the 21st General Hospital, located near Naples, required decortication. By the end of the war, the only casualties in this group who required decortication were those in whom massive clotting had begun shortly after wounding. At this time, the operation was chiefly used in complicated cases of hemothorax and in hemothoracic empyema. The most reasonable explanation of the improvement was the excellent treatment of hemothorax in forward areas, including prompt, vigorous thoracentesis; measures to promote early pulmonary reexpansion; and a material reduction in the number of thoracotomies performed at initial wound surgery for the evacuation of hemothoraces.

While a hemothorax could become infected and empyema could develop early enough to require treatment in an evacuation hospital or even, occasionally, in a field hospital, these complications did not usually ensue until the patient had reached the base section. Both complications are therefore discussed elsewhere (p. 275).

CLINICAL PICTURE AND DIAGNOSIS OF HEMOTHORACIC EMPYEMA

Hemothoraces, as already pointed out, represented the largest hematomas with which the body had to deal in combat-incurred wounds. The fact that they were far too large to vascularize rapidly might very well have played a part in their pronounced tendency to infection.

When infection supervened in either the liquid or the clotted variety of hemothorax, it was not always easy to make a distinction between infected hemothorax and hemothoracic empyema. The precise differentiation depended on changes in the visible characteristics of the pleural fluid. These changes did not always occur immediately (p. 266). The infection was classified as hemothoracic empyema as soon as gross pus or purulent exudate was observed in the aspirated material.

There were distinct differences between the hemothoracic empyema of combat-incurred wounds and the postpneumonic or metapneumonic variety of empyema. In the latter variety, two features were prominent:

1. Infection of the pleural space was initiated upon essentially normal pleural surfaces.
2. The preexistent pathologic changes were in the lung.

Hemothoracic empyema had the following characteristics:

1. The pleural space was seldom normal. It had been altered in varying degrees by the fibrinous deposit that resulted from the presence of blood in the pleural cavity. Posttraumatic empyema was therefore not primarily an infection of the pleura per se but an infection originating in pleural dead space occupied by a hematoma enclosed in a fibrinous capsule.

The antecedent status of the pleural space was a point of great importance. Infection developing within a pleural cavity which has not been the site of a significant hemothorax is always a more favorable type than hemothoracic empyema which develops in a preexisting pleural clot or a neglected liquid hemothorax. In the former type, the restraining membrane or peel commonly observed in all pleural irritative phenomena dates from the onset of the infection. In the hemothoracic type, the peel antedates the clinical evidence of infection and may be well on to maturity before treatment is started.

2. The lung was collapsed and compressed because of the presence of intrapleural blood. There were no changes caused by disease in it, and by the time empyema developed, healing had usually occurred in any pulmonary wound. It was repeatedly observed at decortication that the lung had returned to normal, as evidenced by its ability to expand, even when it had sustained extensive lacerations and contusions. There had been time for this recovery to ensue. When empyema developed in a liquid hemothorax, the average time between wounding and demonstration of pus by thoracentesis or at operation was 15 days. In the clotted variety it was 18 days.

3. The constrictive pulmonary investment—that is, the rind which enclosed the hemothorax—was responsible for failure of the lung to reexpand.

4. The purulent exudate thickened more slowly in the hemothoracic than in the postpneumonic or the metapneumonic variety of empyema.

5. Loculation was more frequent in the hemothoracic variety of empyema, and total empyema occurred more readily.

6. Even in patients with extensive hemothoracic empyema of several weeks' duration, there was no reaction in the costal periosteum, the ribs were never triangular, and the fingers were never clubbed as in the variety of empyema in which there was no antecedent trauma.

All of the circumstances associated with a combat wound are favorable for the development of empyema. They include the wound itself and the tissue destruction that accompanies it; the contamination introduced by the missile and the debris brought into the wounds with it; in many instances, the presence of pathogenic bacteria; tissue necrosis; the presence of an intrathoracic foreign body; pneumothorax or hemothorax, with resulting dead space in the pleural cavity; and the ideal culture medium furnished by a clotted or an organizing hemothorax. Neither chemotherapy nor antibiotic therapy could in themselves overcome these circumstances. Only good surgery could meet the situation.

EMPYEMA IN THE WORLD WARS

There was a vigorous discussion of empyema at the 1946 meeting of the American Association for Thoracic Surgery (*6*), in the course of which much emphasis was put upon the differences in the infections of the pleural cavity encountered in the two World Wars. The presentations on chronic organizing hemothorax, hemothoracic empyema, and decortication were prepared by the thoracic surgeons who had had the widest experience in this field during World War II. The discussion was participated in not only by these surgeons but also by a number of other surgeons, among them Dr. Evarts A. Graham, who had had the widest experience in chest trauma and postinfluenzal empyema in World War I.

Graham contended that no comparison was possible between the empyemas of World War I and World War II because there was no similarity between them. The surgeons of World War I, he said, were called upon to treat empyemas which were, in the Hippocratic sense, true abscesses of the pleural cavity. The empyemas encountered by the World War II surgeons were pleural infections attenuated by drugs. In other words, the World War II surgeons dealt with conditions never before seen. If Hippocrates could listen in on the discussion, Graham concluded, he would not know what the World War II surgeons were talking about.

The surgeons of World War II naturally took issue with this point of view. They contended that hemothoracic empyema was true empyema, and they

pointed out that their first patients, as well as some of their later patients, were treated without benefit of chemotherapeutic or antibiotic agents. Many of these casualties, they emphasized, were very ill and highly toxic, and problems of management were quite as serious as those encountered in World War I.

The clinical and other distinctions between the empyemas encountered in the two World Wars were well stated by Dr. Carl Eggers:

1. Chronic empyema was the chief problem of thoracic surgeons in World War I, while posttraumatic hemothoracic empyema was apparently the chief problem of these surgeons in World War II.

2. The patients with chronic empyema encountered in World War I were chronic invalids. They had survived measles, influenza, lobar pneumonia, and the other diseases that were widespread in Army camps and that were frequently complicated by bilateral bronchopneumonia. They had withstood prolonged sepsis. They had usually undergone drainage operations for acute empyema. Structural organizing changes had frequently taken place in the chest wall, the pleura, and even the lung. As a result, their resistance was materially lowered.

3. In World War II, patients who developed hemothoracic empyema after combat wounds of the chest were usually in good physical condition. They had normally functioning organs. Their chest walls were usually intact or almost intact and were therefore mobile. Their lungs were usually uninvolved; if there was any pulmonary involvement, it was usually traumatic and not infectious. These casualties might have lost blood and been in shock, but their resuscitation had been uniformly excellent, and their resistance was generally good. In short, there was a striking difference in the general condition and the surgical risk presented by the casualties of the two World Wars.

In discussing the procedures possible in empyema in the two wars, Eggers pointed out that it would not have been possible, in World War I, to insert a rib spreader after making the incision, which was part of the technique of decortication in World War II. It would have been impossible because the ribs were usually fused and were firmly embedded in the thickened parietal pleura. Resection of portions of all the ribs overlying the pleural cavity was therefore prerequisite to mobilization of the chest wall. In World War II, the chest wall was practically always mobile. In World War I, the parietal pleura was often half an inch or more in thickness. Mobilization of the compressed lung, the most important surgical objective, had to be accomplished by reflection of the thickened tissue forming the angle of reflection from the parietal pleura onto the lung. Then, if it were possible, the remaining layer of tissue compressing the lung was peeled off. Often this was not possible. Then the solution was to make crisscross incisions into it. Complete reexpansion of the lung occasionally followed this procedure but, as a rule, success was only partial.

The degree of success achieved in individual patients in World War I, Eggers concluded, depended not only upon the surgery performed but upon

the condition of the pulmonary parenchyma. If the lung was fibrotic, as it frequently was, complete reexpansion could not possibly occur. From this standpoint, conditions in World War II were very much more favorable, a point of view which the World War II surgeons present did not accept.

MANAGEMENT OF INFECTED HEMOTHORAX AND HEMOTHORACIC EMPYEMA

General Considerations of Treatment

Aspiration, with or without the instillation of penicillin, was occasionally used in small infected hemothoraces in the Mediterranean theater, but it was never a theater policy. This method was used only when cultures were sterile, compression of the lung did not exceed 25 percent, and the patient's condition was good. If a purulent exudate appeared, drainage was instituted at once. The unwise use of continued aspiration was an invitation to chronic empyema. In World War I, the patients who were thus treated endured months and years of suppuration and, if they survived, eventually required multistaged deforming obliterative operations. Such patients were scarcely ever seen in World War II.[4]

In some European chest centers, a so-called irritating pack was occasionally used in chronic empyemas in which the cavities were small or of moderate size, in the belief that maintenance of an acute inflammatory state would produce an obliterative pleuritis more rapidly. This method, which is usually employed only as a supplement to a small Schede thoracoplasty, was not used in the Mediterranean theater.

Intercostal catheter drainage as the sole method of treatment of empyema was never considered adequate. The catheter was promptly blocked by large amounts of partially degenerated clot, fibrin, and exudate, and drainage simply ceased. Early in the war, some surgeons employed catheter drainage as a preliminary to rib resection, but as experience increased, it came to be appreciated that if drainage was indicated, almost the only contraindication to rib-resection drainage was that the patient was too ill to tolerate it as a primary procedure.

Selection of Therapeutic Method

When treatment of infected hemothorax and hemothoracic empyema became standardized in the Mediterranean theater, three methods were employed:

1. Rib-resection drainage alone.

[4] The basic difference, of course, was that in World War I the empyemas encountered were of the synpneumonic or metapneumonic varieties. In World War II, the empyemas were chiefly caused by infection of hemothoraces. They occurred in healthy pleural cavities and in association with healthy lungs.—F. B. B.

2. Primary decortication; that is, a procedure to eradicate infection or empyema by securing immediate normal expansion of the lung, without preliminary drainage of the pleural cavity.

3. Secondary decortication; that is, a procedure for the same purpose after adequate rib-resection drainage for several weeks.

The choice of treatment depended upon several factors:

1. The size and location of the empyema cavity. If the cavity were small, unilocular, and basal, rib-resection drainage alone was usually adequate.

2. The percentage collapse of the lung and its distribution. To World War II thoracic surgeons, the status of the lung was of primary importance. Their position was based on the truism: "As goes the lung, so goes the pleural space."

If collapse involved 50 percent or more of the lung, primary decortication was the method of choice, particularly if the pulmonary apex was involved in the collapse. Because of the increased technical difficulties if apical collapse ensued after rib-resection drainage, collapse at the apex was considered a more important indication for primary decortication than a similar degree of basal collapse.

The common method of estimating the percentage of pulmonary collapse was based upon the distance of the lung border from the lateral thoracic wall as it was observed in posteroanterior roentgenograms. The measurement was frequently found to be in error and was nearly always found to be a minimal estimate. The lung was usually collapsed for an equal distance from the anterior and the posterior thoracic walls. In most instances, if the lung border did not approximate the lateral thoracic wall by a third of the width of the hemithorax, the collapse was usually found to be 50 percent or more. A consistent lack of correlation was found between the percentage collapse of the lung as determined by roentgenograms and as observed at operation (fig. 94).

3. The status of the patient. A few patients were so seriously ill as the result of massive pleural infection that a procedure of the magnitude of decortication could not be considered as a primary procedure. This operation sometimes lasted 3 hours or more, and there was a considerable loss of blood during decortication of the visceral pleural surfaces.

Most patients treated by primary decortication had had fever to 102° or 103° F. daily for several days or longer before operation. When other features of the illness were favorable, pyrexia was not regarded as a contraindication to its performance. Much more important was the estimation of the general status of the patient and his ability to withstand surgery as shown by simple observations of the color of his skin, his appetite and nutrition, his general strength and alertness, and his response to transfusion.

4. The results of rib-resection drainage when it had been used as a primary procedure. In these cases, it was observed that if satisfactory results were to

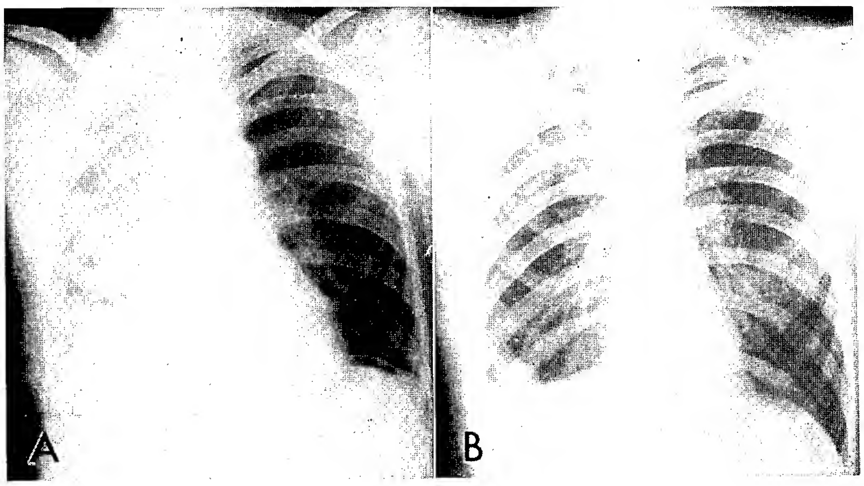

FIGURE 94.—Decortication in hemothoracic empyema. A. Posteroanterior roentgenogram showing original extent of empyema. B. Same, 2 weeks after thoracotomy and decortication, which resulted in complete cure. At operation, degree of pulmonary collapse was found to be considerably greater than indicated in figure 90A.

follow, they would be evident within the first 4 to 6 weeks after operation (fig. 95). If the lung expanded rapidly within that period, so that it seemed reasonable to anticipate continued complete obliteration of the cavity, no further surgery was considered necessary. If progress during this period was not satisfactory (fig. 96) and the collapse of the lung remained at 50 percent or more, secondary decortication was considered indicated, not only to prevent possible or probable chronic empyema but also to reduce the duration of pleural suppuration.

These considerations applied to all cases of empyema as well as to infections of clotted hemothoraces. Because of the tendency to loculation in both lesions, there was little reason for assuming that all septa would be broken and all loculi drained through the relatively small wound made at rib resection. This was true whether the purpose of the procedure was to provide an outlet for frank pus or for drainage of a clotted hemothorax. Rib-resection drainage was a satisfactory procedure, in short, only when the cavity was so small that all parts of it were readily accessible.

Multiple empyemas associated with fistula formation in a traumatized lung that had fully reexpanded offered a real therapeutic challenge. The precise origin of the pathologic process in such cases was frequently not clear. The blowouts might have occurred primarily along the missile track. Another theory was that a primary vascular injury might have resulted in areas of pneumomalacia that later ruptured, thus giving rise to isolated fistulas with separate encapsulated pockets of empyema.

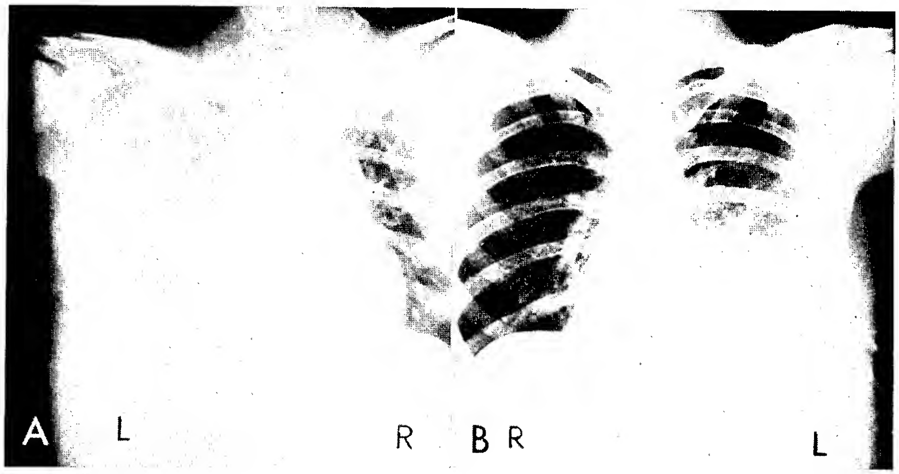

FIGURE 95.—Management of hemothoracic empyema by rib-resection drainage. A. Posteroanterior roentgenogram showing massive liquid hemothoracic empyema on left just before operation. B. Same, 4 weeks after institution of drainage by rib resection. Lung is now almost completely expanded. This patient went on to recovery without further surgery.

Decortication was obviously not the solution in this group of cases, and great care was required in the institution of drainage. A misplaced incision could result in unnecessary mutilation or even introduce a real threat to life. Attempts to drain one cavity through another, however closely adjacent the two cavities might be, were usually ill-conceived and might well cause complications by tearing into a lung that was normal or only slightly involved. The best technique in this kind of case was drainage by multiple rib resections.

DECORTICATION OF THE LUNG

Development and Rationale

The first decortication recorded in World War II was performed in the North African Theater of Operations, U.S. Army, in April 1943, by Major Burford, on a patient with an uninfected organizing hemothorax, 5 weeks after injury (vol. I). The smooth recovery and successful end result in this case elucidated many previously obscure problems of clotted hemothorax. Thoracotomy had sometimes been undertaken before this date for removal of the clot, but the operation was seldom successful, as might have been expected, for it made no attack upon the essential pathologic feature of clotted hemothorax; that is, the fibroblastic membrane or peel. It was the continued presence of this constrictive pulmonary investment that prevented reexpansion of the lung compressed by it.

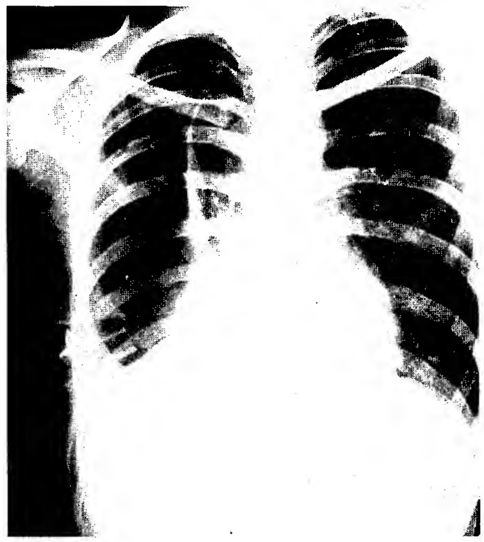

FIGURE 96.—Posteroanterior roentgenogram showing massive liquid empyema on right side 4 weeks after institution of rib-resection drainage. Lung is still collapsed. Patient later required secondary decortication.

The rationale of decortication was incontrovertible:

1. The continued presence of an organizing hemothorax prevents pulmonary reexpansion.
2. The intrapleural mass must therefore be removed.
3. A line of cleavage exists between the pleural surfaces and the membrane until such time as the process, if not interrupted, becomes chronic in the pathologic rather than in the chronologic sense.
4. Decortication, which removes the compressing membrane, if performed before the process becomes chronic, will result in immediate and total pulmonary reexpansion and will also obliterate all pleural dead space.

In the beginning, decortication was undertaken only on the indication of uninfected organizing hemothorax. At a number of operations, however, unexpected loculations of pus were found, and inadvertent decortication for infected hemothoraces and hematothoracic empyema proved the suitability of the operation for both of these conditions. The extension of the operation to these conditions was perfectly logical. The basic pathologic process was the same in both. Microscopic examination of the rind over the pleura in early empyema showed it to be identical, cytologically and chronologically, with the rind in noninfected hemothoraces.

With the advent of penicillin and the demonstration of its usefulness by Maj. Champ Lyons, MC, the next step in the evolution of decortication was natural, the use of the operation without preliminary drainage in massive empyema. The first deliberate primary decortication for hemothoracic empyema was performed by Maj. (later Lt. Col.) Paul C. Samson, MC, under penicillin protection, in March 1944. It was a complete success.

Decortication was then extended to cases in which concomitant lesions justified operation even if the size of the clotted hemothorax or the empyema present would not, in themselves, have warranted the operation. In many residual empyemas, other persistent pulmonary processes required surgical correction, including obliteration of bronchial fistulas; wedge resections for multiple fistulas; or, occasionally, the same procedures for posttraumatic abscesses.

The rationale of early decortication in properly selected cases of sterile organizing hemothorax, infected hemothorax, and posttraumatic or hemothoracic empyema rapidly led to the concept that it was not tenable to consider that a patient with massive hemothorax was convalescing satisfactorily merely because he showed no signs of infection. Such a point of view took no cognizance of the primary concern of the surgeon; namely, the early restitution of pulmonary function and the prevention of the crippling effects of chronic fibrothorax.

The most effective reply to the arguments of those who advocated a more conservative approach to the therapy of posttraumatic empyema was the not insignificant case fatality rate in adequately drained cases in which progress was apparently satisfactory. Progress in even the most competently managed case was unpredictable, and the road from drainage to complete cure was beset with many dangers. Chronicity could develop at any stage, and at the best, the elapsed time between drainage and cure was a matter of many weeks, and often of many months.

The rediscovery and reapplication of total pulmonary decortication (vol. I) to organizing hemothorax and to hemothoracic empyema resulted in a prompt decrease in the duration of recovery after chest wounds and a reduction in the number of potential pulmonary cripples. In properly selected cases, decortication was almost invariably followed by prompt eradication of intrapleural fibrosis and sepsis and prompt pulmonary reexpansion.

As Col. Edward D. Churchill, MC, pointed out in the discussion of decortication at the 1946 meeting of the American Association for Thoracic Surgery (p. 273), the principle for which the Empyema Commission fought in World War I was to wait to establish drainage until a generalized empyema had become localized. In World War II, the procedure was the exact reverse: It was to take a localizing empyema and convert it into a generalized pleural contamination in order to achieve prompt reexpansion of the lung. When the principle was thus stated, Colonel Churchill concluded, it was as startling as it was important.

In the excitement of this discussion, three points of major importance in the management of the hemothoracic empyema encountered in World War II were not explicitly stated:

1. There was no emphasis on the status of the mediastinum. As Graham had pointed out in World War I, when the mediastinum had become fixed,

drainage was indicated and safe. When it was still labile, drainage was not indicated and could be lethal.

2. The status of the pleural space depended upon the status of the lung, according to the truism, already mentioned: "As goes the lung, so goes the pleural space."

3. The point emphasized in Colonel Churchill's discussion, that it was safe to take a localizing empyema and convert it into a generalized pleural contamination in order to achieve prompt reexpansion of the lung, was possible only because penicillin was available and was capable of protecting the pleural cavity against bacterial invasion.

Indications

Before the concept of decortication for organizing hemothorax, infected hemothorax, and empyema could be properly formulated, it was necessary to bear in mind certain fundamental facts:

1. The essential nature of the pathologic process. The demonstration of the fibroblastic membrane that invested the pleura explained the chronicity of many hemothoraces with infection, made clear the object of treatment, and pointed to the procedure that would achieve the desired results.

2. The efficacy of penicillin in protecting against and controlling invasive infection, so that surgery could be safely applied at the optimum time to secure maximum functional results.

3. The selection of cases on the basis of strict indications. This was not a procedure for promiscuous use. After decortication was first introduced, the initial wave of overenthusiasm, as often happens, led to its use in some patients in whom it was not indicated. The original excess of enthusiasm was soon tempered by experience, and the scope of the operation was properly delimited and its indications defined.

There were four chief indications for decortication:

1. *Uninfected organizing hemothorax.*—Patients in this group were treated conservatively for periods ranging from 3 to 6 weeks. During this time, repeated aspirations were carried out. Even if all the blood in the pleural cavity could not be removed and some clotting had already occurred, the removal, from time to time, of as little as from 50 to 100 cc. of currant-jelly-like material through a large caliber needle was found to be advantageous. Breathing exercises (vol. I) were also instituted, in an effort to aid reexpansion of the lung.

Between the third and sixth weeks of conservative treatment, the patient's status was carefully appraised. If aspiration was yielding only a few cubic centimeters of blood and serum and if roentgenograms failed to show progressive improvement, decortication was regarded as indicated if the patient presented some or all of the following symptoms and signs: Diffuse pulmonary pain or discomfort; dyspnea on exertion; and poor thoracic expansion, with

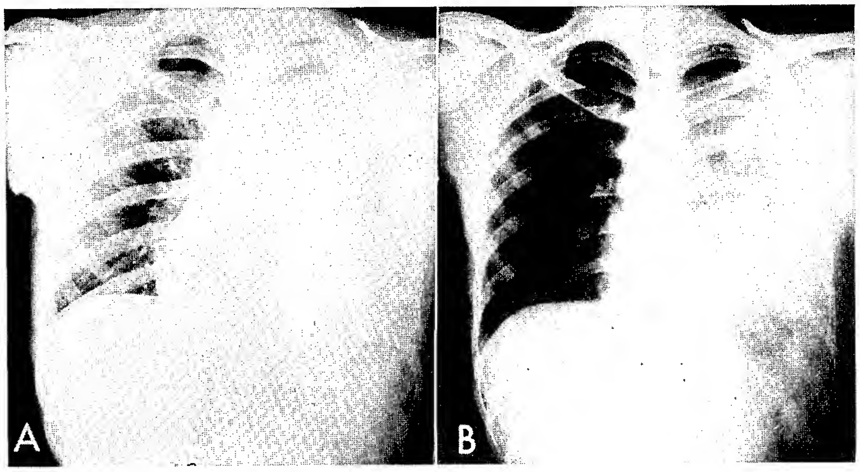

FIGURE 97.—Management of clotted hemothorax with retained foreign body. A. Posteroanterior roentgenogram showing extensive left hemothorax, with foreign body in left lung. B. Same, showing clotted hemothorax of moderate size after 2 weeks' trial of aspiration. A clotted hemothorax of this size would not, in itself, have constituted sufficient indication for decortication at end of 2 weeks, but surgery was considered indicated because of missile in lung.

retraction and narrowing of the intercostal spaces. A generalized hazy appearance on the roentgenograms provided additional support for decortication.

Patients with organizing hemothorax associated with retained foreign bodies a centimeter or more in diameter often presented good expansion of the upper lobe by the third or the fourth week, although a lower lobe might still be partly compressed by organizing hemothorax. In cases of this kind, the combination of an organizing hemothorax, even of moderate degree, and of a retained foreign body was regarded as sufficient indication for decortication and removal of the missile (figs. 97 and 98).

2. *Infected organizing hemothorax.*—Decortication was undertaken, as soon as the patient's condition permitted, in all cases in which the pulmonary collapse was more than 25 percent, particularly if the collapse involved the apex. Although infection sometimes became evident by the 10th to the 12th day after wounding, it usually manifested itself at a somewhat later date. Positive smears or cultures frequently could not be obtained, and presumptive evidence of infection had to be based on signs of increasing toxicity, mounting fever, or rapid enlargement of the hemothorax. Massive clotting was likely to be present in these cases, and a policy of delay often led to the development of empyema.

Many surgeons took the position that bacteria were consistently present in hemothorax, even if cultures were negative and even if frank suppuration did not supervene. If this concept were correct and the intrapleural mass

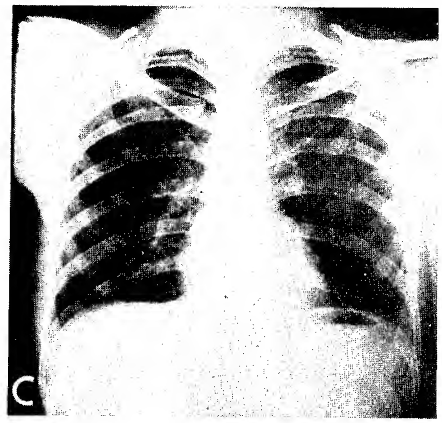

FIGURE 97.—Continued. C. Same, 2 weeks after decortication. Progress after operation was entirely satisfactory and patient went on to complete cure.

were left in situ, it seemed logical to postulate that true latency might result from foci of infection left deep in the hemothorax.

If this latter hypothesis were correct, then it could be further postulated that in the postwar period, patients with fibrothorax or neglected organizing hemothorax would present the persistent roentgenologic finding that in the past has been erroneously termed "thickened pleura." It is characteristically present in patients subject to recurrent febrile episodes caused by recrudescence of activity in foci of infection in the chest, as well as in patients who have become chronic respiratory invalids.

3. *Posttraumatic* (*hemothoracic*) *empyema.*—As already pointed out, the distinction between hemothorax with infection and frank hemothoracic empyema was not great in many cases. In frank empyema, the infection might have been present for a longer period of time or might be more virulent. In general, the patients were more critically ill than those with infected hemothoraces, and the aspirated material was more grossly purulent. All the patients on whom decortication was performed on the indication of empyema had clinical evidence of infection; that is, fever, anorexia, malaise, and other signs of toxicity. The majority were acutely and seriously ill, and at operation all were found to have purulent fluid in the pleural cavity.

The type of organism recovered from the pleural fluid was not a factor in the decision for or against decortication. Clostridial empyemas were treated by the same routine as other empyemas. The percentage of negative cultures was probably no greater than would be encountered in any series of empyemas. Negative cultures were to be expected after chemotherapy and antibiotic therapy had been employed.

Focal points of intense reaction were occasionally seen in hemothoracic empyema, and miliary abscesses were occasionally observed in the older portion of the organizing clot. On the whole, however, these layers (fig. 79) were remarkably free from inflammatory reaction. For all practical purposes, the pleura and the layers of adjacent organized clot, with their blood supply, had

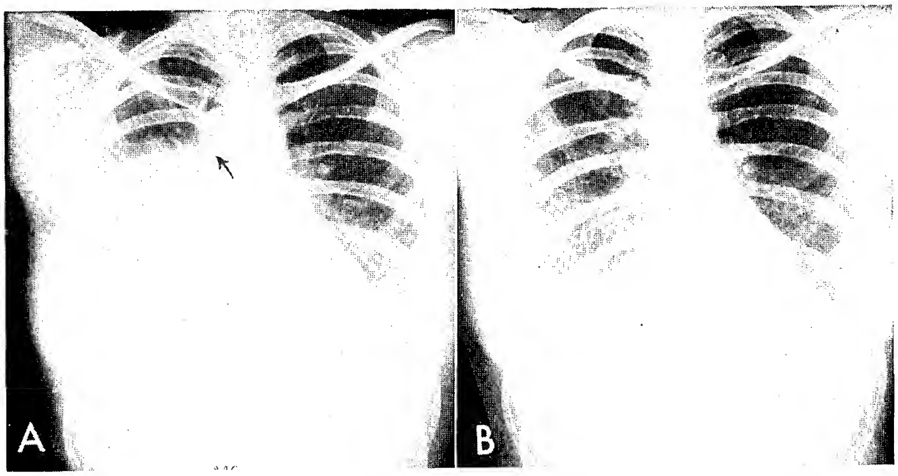

FIGURE 98.—Management of clotted hemothorax with retained foreign body. A. Posteroanterior roentgenogram showing clotted hemothorax on right, without infection, and foreign body in right lung. B. Same, 2 weeks after decortication and removal of foreign body. There is no residual hemothorax, and lung is fully expanded.

cleared themselves of infection. This observation helps to explain why such good results could be obtained by decortication even when there was frank suppuration in the center of the organizing mass.

4. *Other indications.*—Persistent bronchopleural fistulas, esophagopleural fistulas, and transdiaphragmatic biliary fistulas were not frequent, but all played their part in the genesis of chronic empyema and therefore demanded energetic management. Early decortication, with excision and closure of the fistula, gave excellent results. In a few cases, decortication under penicillin protection was combined with the excision and closure of small intrapulmonary abscesses (up to 5 cm. in diameter) associated with empyema.

Penicillin, with its established bacteriostatic properties and its resultant ability to diminish the dangers of invasive infection at operation in the presence of acute intrapleural infection, proved to be the adjunct which had long been desired to render early surgery safe in such cases. Perhaps the most valuable role of penicillin was in the management of chronic empyema, in which it afforded efficient protection against spreading infection when a radical operation such as decortication was undertaken for the obliteration of a chronic empyema cavity.

A precise estimate of its benefits was naturally not possible. It seemed reasonable to assume, however, that, when the surgeon was obliged to work in a potentially or actually infected field, penicillin protection often prevented serious wound infections and other complications. When it became available, it was possible to pursue a rational plan of therapy in infected hemothorax and hemothoracic empyema, directed toward the achievement of (1) early

pleuropulmonary lysis, (2) total ablation of infected tissue, (3) complete pulmonary reexpansion, and (4) absolute obliteration of residual pleural dead space. Under penicillin protection, all of these objectives could be achieved by a procedure relatively free from the risk of septic dissemination.

When penicillin became available, in the spring of 1944, the indications for decortication in hemothoracic empyema became stabilized. Rib resection with drainage was considered wisest when the pleural infection was limited to the basal portion of the thorax or when it was small and definitely encapsuled. If these empyemas were drained adequately, persistent cavitation seldom developed. If complete obliteration of the cavity and complete pulmonary reexpansion did not take place promptly, however, the patient was regarded as a candidate for decortication.

Preliminary rib-resection drainage was also used in patients who were too ill and too toxic to be subjected initially to open thoracotomy and decortication.

Decortication without preliminary rib-resection drainage had a number of advantages:

1. Complete pulmonary expansion occurred at once, with the immediate elimination of all intrapleural dead space.
2. Chronic empyema, which was a distinct possibility after rib-resection drainage, was prevented.
3. Weeks and months of disability were eliminated, as was the risk of serious and even fatal complications, such as brain abscesses.
4. The patient was spared a great deal of discomfort and inconvenience, and the hospital staff was saved the time and effort required by repeated dressings.

At least three factors were responsible for the poorer results in secondary decortication:

1. The patients requiring preliminary drainage were, as a group, more seriously ill than those who did not require it. In particular, they were likely to be much more toxic.
2. The intrathoracic wounds were generally more severe.
3. The interval between wounding and decortication was longer in secondary decortications, because of the original poor condition of the patients and the additional time necessary for the drainage operation and recovery from it.

Two questions arose in connection with the selection of cases for decortication:

The first question was whether it would be possible to develop a peel in the particular case. This was not a question that could be answered positively. Timing of surgery played an important part in the possibility. Roentgenograms did not furnish a clue, nor did a study of the parietal pleura at a preliminary drainage operation. As a matter of fact, the pleural membrane was

usually thicker, and the pulmonary collapse more pronounced, than the films suggested. Unsuspected pleural pockets were also often found.

The answer to the second question, whether or not the lung would reexpand, depended upon the extent and type of pulmonary damage and whether or not infection was present. The description written by the forward surgeon might be helpful in estimating the extent of the pulmonary injury. If the injury was a contusion, a roentgenogram taken immediately afterward, before the development of hemothorax, was also helpful. Again, timing was a factor. If decortication were performed too soon after wounding, the lung would not have had time to heal after injury and regain sufficient elasticity to permit adequate reexpansion. If a homolateral pneumonitis was present, decortication was not performed until it had cleared up, not only to give the lung a chance to recover but also to avoid the risk of introducing organisms into the bloodstream by opening the lung; septicemia could easily result. As these statements indicate, the expansile ability of the lung could not be settled by generalizations but had to be estimated in the individual case.

Timing

As early as 1904, Violet (*7*) had stated that if decortication were to be employed, it should be employed promptly, as soon as it was evident that an empyema would not undergo spontaneous cure and before the walls of the cavity had become rigid and separated by too wide a space. Lilienthal (*8*), in 1915, had resorted to the operation in a matter of weeks, but most American surgeons who used it believed that it should be employed only after many months had elapsed and after other methods of treatment had failed. In 1928, Lockwood (*9*) reported that there were more failures in cavities that had lasted from 6 to 18 months than in those of longer standing. He had himself achieved partial success with decortication in an empyema of 21 years' standing, and he had had some good results in cases which had lasted for 16 years.[5]

The surgeons in the North African theater who first performed decortication for organizing hemothorax originally thought that a period of at least 8 weeks should elapse from wounding to operation. Their reasoning was that clearing of the pleural space would occur in a great many instances within this period. It proved fallacious as applied to all but small cavities. Eventually, by the trial-and-error method, it was found that the optimum period for operation in uninfected chronic traumatic hemothorax was between 3 and 5 to 6 weeks after wounding. If infection occurred, especially if it were of the rapidly developing type, operation was done earlier.

The timing was logical for several reasons:

1. If operation was deferred for 5 or 6 weeks, many patients who originally had seemed candidates for decortication showed satisfactory resolution. The

[5] These observers, it should be noted, were dealing with the type of empyema associated with the pneumonias, not with the hemothoracic variety of World War II.—F. B. B.

size of the clot played a part in this decision. In perhaps 90 percent of all decortications, the intrapleural clot exceeded 1,000 cc. in volume. It was not conceivable that a mass of such size could be absorbed within 5 or 6 weeks, or even within a much longer period.

2. In uninfected cases, a rind less than 3 weeks old was usually so thin and so poorly defined that it had to be wiped off the pleural surface or stripped away piecemeal. It could seldom be removed in toto, as was desirable.

3. If operation was postponed for more than 5 or 6 weeks after wounding, the increasing cellular intimacy between the rind and the visceral pleura made the operation technically difficult. By the fifth or the sixth week, hemo-organization and fibroplasia had advanced to the point at which the membrane was substantial enough to be handled with ease. Extensions into the pleural and subpleural tissues, and sometimes complete synechiae between the rind and the pleura, made clean separation difficult and even impossible, and tears of the lung were frequent.

The length of time necessary for complete definition of the rind varied from patient to patient. In some instances, decortication was performed successfully within 10 to 14 days after wounding. At the other extreme, it was also performed successfully from 12 to 14 weeks after wounding, and the time was extended to even longer periods in some hospitals in the Zone of Interior (p. 405). On the whole, the best results were obtained within 3 to 5 or 6 weeks after wounding.

An obvious advantage of performing decortication early in uninfected organizing hemothorax was that infection was prevented at the same time that recovery was expedited. The tendency to infection and prolonged disability in organizing hemothorax weighed heavily in the decision to perform decortication.

Since the optimum time for decortication was within 3 to 6 weeks after wounding, evacuation to the Zone of Interior was not usually possible, and decortication had to be performed on most patients in oversea hospitals. It was preferably performed in a base hospital or chest center, but occasionally, if fighting had slowed down and evacuation to the rear was delayed, it was performed in an evacuation hospital.

Preoperative Preparation

The excellent results secured by decortication in World War II might lead those unfamiliar with the operation to conclude that it was not major surgery. The conclusion would be completely unwarranted. The operation was always one of magnitude and was never performed without careful preoperative preparation.

Preoperative measures included:

1. Identification of the infecting organism.

2. Complete roentgenologic investigation, to determine the presence of retained foreign bodies, bronchopleural fistulas, lung abscesses, and other complicating lesions.

3. Replacement therapy. Daily transfusions were given, in amounts of 500 to 1,000 cc., until the hematocrit level was 40 or higher.

4. Nutrition. The nutritional status was brought to as near normal as possible by a high-caloric, high-protein diet. The serum protein is always low in any condition in which proteins are lost by exudation, and plasma infusions, as well as a protein dietary supplement, were therefore employed as indicated.

5. Penicillin therapy. Penicillin was given intramuscularly in amounts of 200,000 units every 24 hours (25,000 units every 3 hours), usually for 48 to 72 hours before operation. Some patients were apparently safely prepared in 24 hours, though this was probably not long enough in most cases, and other patients received penicillin for 14 days or more, which was usually unnecessarily long. It was useless to wait for defervescence. That could come only with the extirpation of the infected focus.

All of these measures were important. Compromise with any of them would have put the morbidity and mortality of decortication on a prohibitively high basis. The unavailability of most of these supplemental measures, as pointed out elsewhere (vol. I), furnishes at least part of the explanation of the poor results of decortication when it was first employed.

Principles

The principles upon which decortication was based were as follows:

1. The object of the operation was to peel off the membrane immediately overlying the visceral pleura and to remove all blood clot and fibrin in the pleural cavity, thus permitting complete reexpansion of the collapsed lung.

2. To accomplish this, adequate exposure was essential.

3. The first step of the procedure was to obtain a proper plane of cleavage between the peel and the visceral pleura, beginning at the junction of the collapsed lung with the chest wall or over the undamaged portion of the lung.

4. The peel was removed by blunt dissection, carried out digitally or with gauze.

5. The success of the operation depended upon complete freeing of the lung wherever it was directly adherent to the thoracic wall and the mediastinum, as well as along the fissural margins, so that complete circumferential reexpansion could be obtained. The apex of the lung had to be freed, so that it would fill the cupola of the pleural cavity. The operation could not be regarded as a failure if the diaphragm was not decorticated and mobilized, but if it could be released, pulmonary efficiency was greatly enhanced. Particular attention was paid to the redevelopment of the costophrenic sulcus.

6. Generally speaking, the greater the area of lung decorticated, the better were the results.

7. Bronchopleural fistulas had to be closed, especially fistulas in the upper pulmonary lobe. If this lobe remained collapsed, the operation was a failure.

8. If intrapleural bleeding occurred and complete hemostasis was not obtained, the status of the pleural cavity would be about as it was before operation. It was best to leave the parietal pleura in situ if stripping it seemed likely to cause excessive bleeding. The membrane in this area was thicker and more vascular than elsewhere, and bleeding in it was not controlled by pulmonary reexpansion. It therefore became the practice to leave it in situ in most cases, on the ground that removal increased the surgical risks unnecessarily and did not appreciably increase the benefits of operation.

Anesthesia

Decortication was performed under cyclopropane or nitrous-oxide-oxygen-ether anesthesia, always by the endotracheal technique. The services of a trained anesthesiologist, experienced in thoracic surgery, were mandatory.

It was part of his task to administer blood to the patient during the operation, usually in the amount of 1,000 to 2,000 cc., according to the indications. It was just as important for the patient to leave the operating room with the hematocrit approximately normal as it was for it to be raised to normal level before operation. This aspect of blood transfusion was quite as essential in the end results of decortication as was its shock-preventing function.

Bronchoscopy was practically always performed at the end of the operation. It was never omitted if moisture was audible after catheter aspiration or if pulmonary reexpansion had been difficult.

TECHNIQUE OF DECORTICATION

Management of unhealed wounds.—Unhealed wounds on the hemolateral thorax were either closed before decortication was undertaken or were excised and closed just before the incision for decortication was made. If the two operations were done at the same sitting, fresh instruments were used for decortication.

The detailed technique of decortication was as follows:

Incision and exposure.—The patient was placed in the lateral decubitus position, with the affected side uppermost. A posterolateral intercostal incision, just below the angle of the scapula, was most often employed (fig. 99). It usually permitted excellent exposure, without section or resection of any ribs. There was no serious objection to removal of a rib posteriorly, but if an anterior incision was employed, costal resection was not necessary. Most decortications were done without section or resection of a rib unless previous surgery or comminuted compound fractures made it advisable to remove all or part of one or more (fig. 100). Exposure was usually entirely adequate without

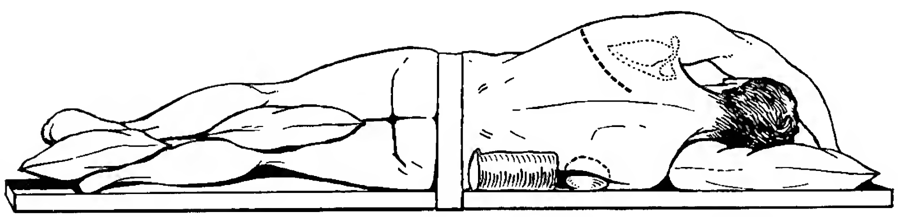

FIGURE 99.—Technique of decortication. Position of patient on operating table and site of incision.

costal mutilation, and intercostal incision, with retraction of the serratus anterior, was the method of choice.

Entrance to the chest was usually gained through the sixth intercostal interspace, but either the fifth or the seventh interspace could be used if a more generous intrathoracic exposure was thought desirable at either the apex or the base. Selection of the incision depended somewhat upon the individual thoracic habitus but was chiefly dependent upon the extent and the location of the process to be dealt with.

The first view of the interior of the chest, after the retractors had been slowly spread and full exposure had been secured, was of varying amounts of liquid or clotted blood, fibrin, or purulent exudate.

Release of lung.—As soon as the pleural cavity was entered, the lung was freed widely from the parietal pleural rind about the region of the incision. If this precaution was not taken, extensive damage to the lung could be caused when the ribs were separated. Great caution was necessary if there were many adhesions.

Since the lung was often compressed into the posterior gutter, much of the separation at this point was behind and mesial to the membranous envelope. Since the peel on the parietal pleura was usually left in situ (p. 289), it was important during the process of paraincisional mobilization of the lung that the proper line of cleavage be established. This was between the layers of the fibroblastic membrane and not between the pleura and the peel (fig. 79).

As soon as the necessary dissection had been accomplished, rib spreaders were introduced and the blades were widened gradually. It was important that they be spread gradually, especially if a rib had not been sectioned or resected, to allow for muscular relaxation and prevent costal fracture, pleural tears, and muscle avulsion.

Exploration.—All liquid exudate, fragments of blood clot, and masses of fibrin were evacuated, and all loculi were broken down. The cavity was then carefully examined for retained foreign bodies, fragments of cloth and other debris, and bronchopleural fistulas. After it was certain that a fistula did not exist, the cavity was thoroughly irrigated with physiologic salt solution.

Further inspection was then undertaken. All anatomic landmarks were obliterated, and the underlying lung was relatively immobile. Typically, the

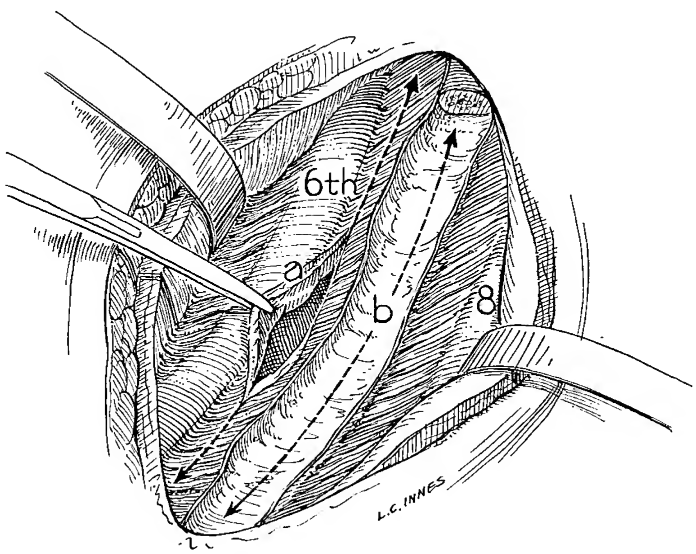

FIGURE 100.—Techniques of decortication showing alternate methods of entering pleural cavity: Intercostal incision (a), and rib resection (b). The sixth intercostal space was the most common site of entrance into the pleural cavity for decortication.

inner or younger surface of the peel had a brownish-red surface, with the appearance of shagreen leather. The contours were smooth.

Decortication.—The first step of decortication was a sharp incision through the fibroblastic membrane down to the visceral pleura (fig. 101). This step was facilitated if the anesthesiologist used moderate positive pressure, to brace the lung against the incision. The incised edges of the membrane were grasped by forceps and decortication was begun. As soon as the peel was completely disrupted in any segment, herniation of the underlying lung, under pressure, through the incision demonstrated the desired plane of cleavage (fig. 102).

Once a cleavage plane had been established between the organizing peel and the visceral pleura, dissection was continued digitally, or with small, firmly packed gauze pushers, or with small bronchoscopic sponges attached to long hemostatic forceps (fig. 103). The main pressure was always directed toward the rind. If the fingers were used, the palmar surfaces were turned toward the rind, and dissection was accomplished by sweeping motions. The pleura underlying the peel was nearly always thin, transparent, and expansile, and beginning reexpansion of the lung could be observed almost as soon as the regional peel was released.

Oozing was likely to be considerable from the visceral pleura, because of the numerous capillaries torn during the dissection and the gaping ends left on

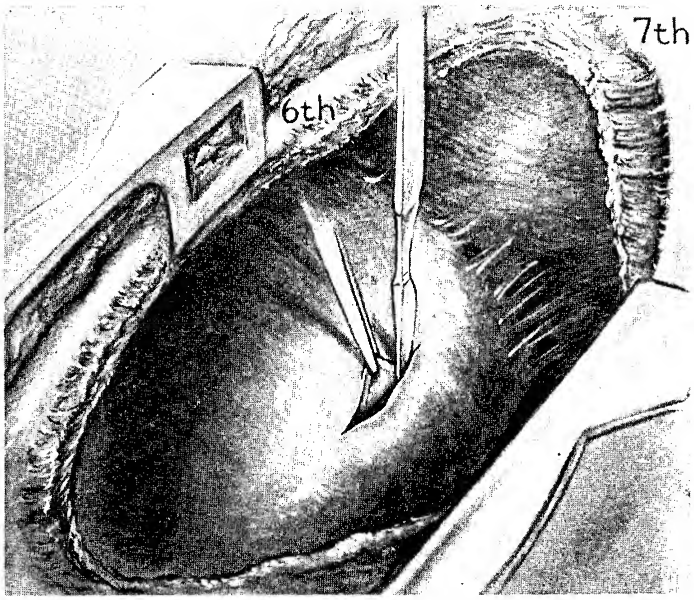

FIGURE 101.—Technique of decortication. Sharp incision through fibroblastic peel down to visceral pleura. Edges of incision are now grasped with instruments, and dissection is begun.

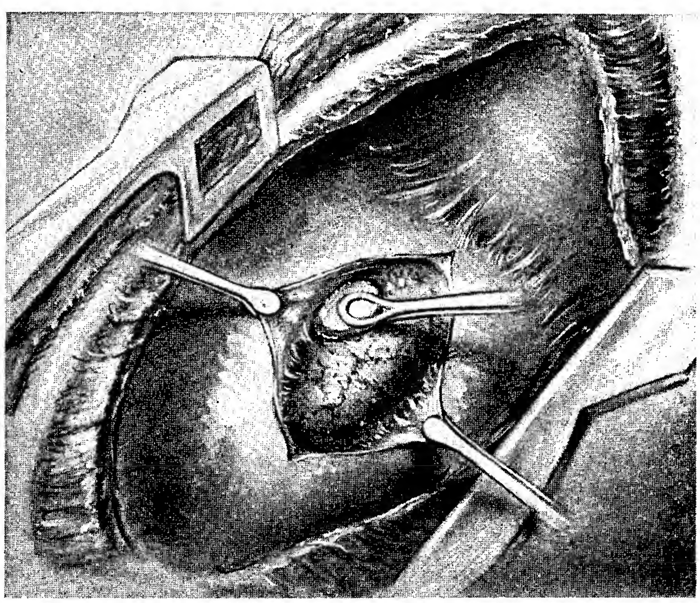

FIGURE 102.—Technique of decortication. Herniation of lung through incision in peel as anesthesiologist uses moderate positive pressure. Majority of lung is still compressed by intact peel.

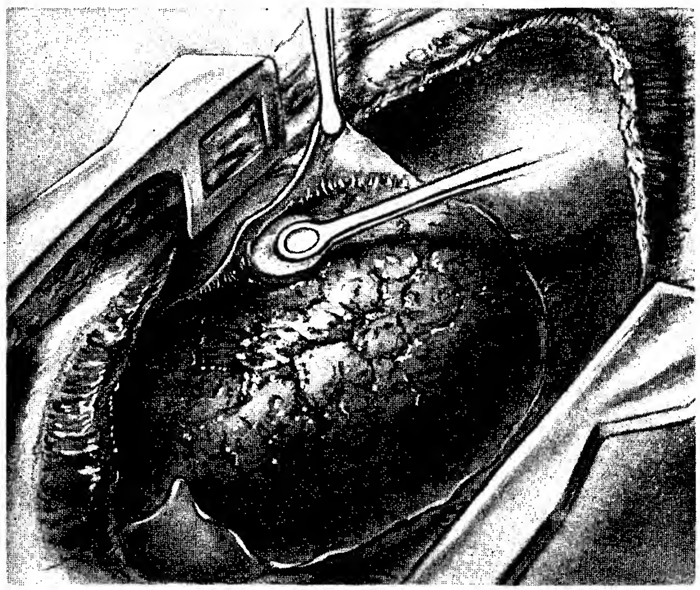

FIGURE 103.—Technique of decortication. Removal of peel by blunt dissection. At this point in the operation, nearly all of the peel has been dissected free from visceral pleura and elevated. Exposed pleura is grossly normal, as is lung.

the pleural surface. It could usually be controlled by warm, moist packs, supplemented by gentle pulmonary expansion under positive pressure.

If the peel was several weeks old, it was usually laminated, and great care had to be taken that the pleura was exposed in every area and that no laminations were left in situ. Reexpansion was inhibited if this precaution was omitted. These scattered islands, while thin, were surprisingly tough, and their removal was essential, for they caused crossings and infoldings of the lung that materially hampered complete pulmonary reexpansion. Crosshatching of the membrane, with piecemeal removal, was not a satisfactory substitute. If islands of thin, tough membrane remained in situ after removal of the primary peel, the correct procedure was to remove them separately.

Decortication was carried to the edge of the collapsed lung, where the peel was reflected onto the parietal pleura. After the fissures and apex had been freed, the lung was separated from the diaphragm, mediastinum, and pericardium, down to the hilus and the pulmonary ligament. This was another extremely important step of the procedure.

The diaphragm was almost always elevated and fixed. If it could not be decorticated completely without difficulty, it was freed circumferentially and thus mobilized. Decortication was never omitted if diaphragmatic disruption or fistula formation was suspected.

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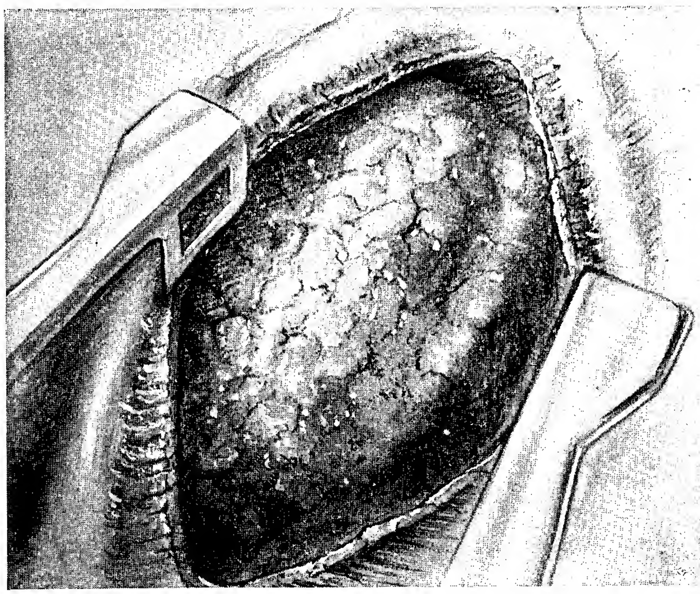

FIGURE 104.—Technique of decortication. Lung completely liberated. When inflated by positive pressure, it fills the hemithorax.

The costophrenic and cardiophrenic sulci were examined, to make sure that they were free of clots and membrane. Their reestablishment increased the motion of the diaphragm and aided in pulmonary reexpansion.

As already mentioned, no attempt was made to remove membrane adherent to the parietal pleura because of the risk of bleeding (p. 290). The costal segment of peel, however, was scraped and scrubbed with gauze, to remove fibrin and to provide a smooth surface. Great care was taken in decorticating the fissural margins, about fistulas, and at the sites of healed pulmonary lacerations. Transdiaphragmatic fistulas were excised and closed.

Management of the lung.—After the initial release of the lung, it was expanded at intervals throughout the operation under increased positive pressure. This gradual method was preferable to attempts at sudden, complete reexpansion at the end of the operation. Such attempts were always ill-advised and could be harmful.

The visceral pleura was kept moist, and atelectatic areas of the lung were gently stroked as it was reexpanded. As a rule, the lung almost completely filled the pleural cavity before the chest was closed (fig. 104), though it was sometimes necessary to rearrange the lobes before they occupied their normal positions.

After the lung had been completely freed, any necessary pulmonary surgery was carried out. Although every effort was made to protect the visceral pleura, it was almost impossible to avoid small tears and areas of traumatism.

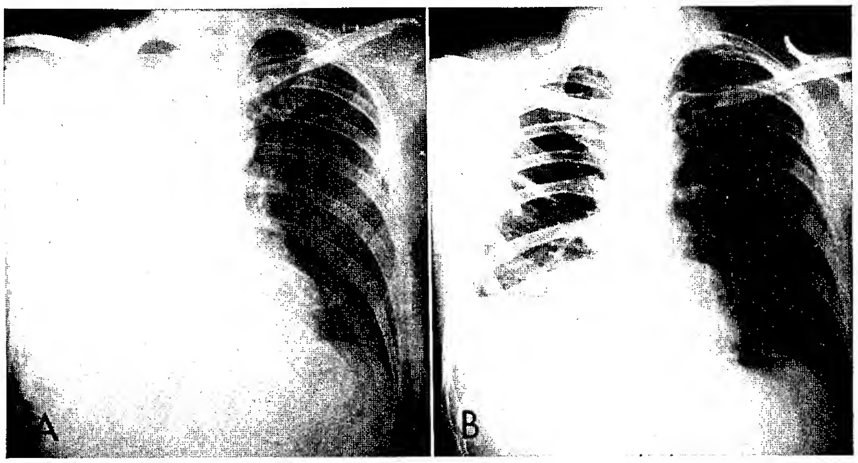

FIGURE 105.—Management of clotted hemothorax by decortication. A. Posteroanterior roentgenogram showing massive clotted hemothorax on right after 4 weeks of observation without improvement. B. Same, 4 weeks after primary decortication. There is no residual hemothorax. Foreign bodies are in chest wall.

The leaks were plugged with fibrin foam or repaired with interrupted sutures of fine silk on atraumatic needles. If tears were overlooked, or if plugs and repairs were not completely successful, the multiple drainage provided at the end of the operation could be depended upon to maintain expansion until the openings were occluded.

Single superficial fistulas were closed after the edges had been freshened. Long sinus tracts were laid open as far as possible, and the lining membrane was curetted before the lung was closed in layers. Superficial closure of sinus tracts was not adequate.

Rib fragments in the lung, foreign bodies in the chest wall (figs. 105 and 106) and lung, and indriven rib fragments were also removed if their size warranted it or if they were readily accessible. It was seldom possible to identify intrapulmonary foreign bodies while the lung was still compressed by the rind of an organizing hemothorax, but they could usually be located and removed without difficulty after decortication (fig. 107).

Infected hematomas and lung abscesses were usually opened, and the necrotic lining membrane was dissected free and removed. The remaining dead space was obliterated by closure in layers with fine silk, nylon, or cotton.

A routine search for areas of infolding (p. 183) was carried out at the conclusion of all decortications. Exploration was particularly necessary when, although the pleura appeared grossly normal, the lateral fringe was abnormally blunt or the lingula was unusually short or a lower lobe was relatively small.

In all correctly performed decortications, the lung was freed from its points of attachment along the parietal or the diaphragmatic pleura; when this had been accomplished, areas of infolding were promptly evident. The freeing

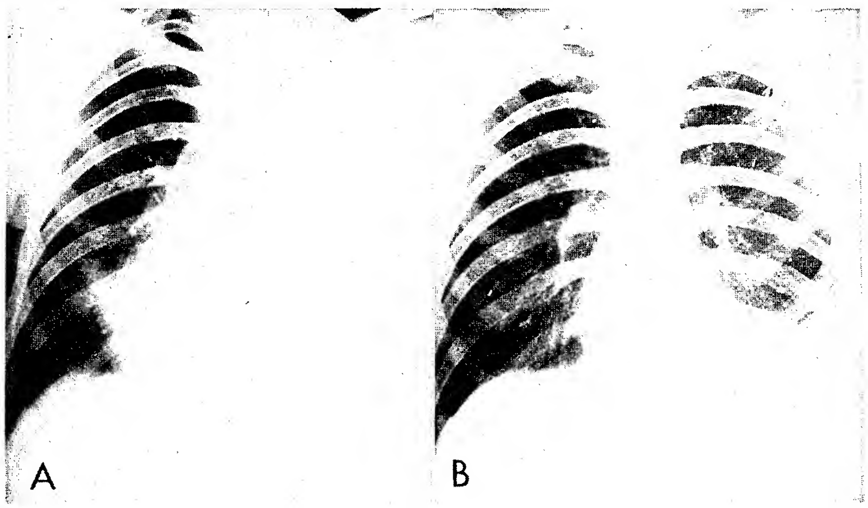

FIGURE 106.—Management of massive liquid hemothoracic empyema. A. Posteroanterior roentgenogram showing hemothoracic process in left hemithorax. B. Same, 4 weeks after primary decortication. Foreign bodies are in chest wall. Complete cure resulted.

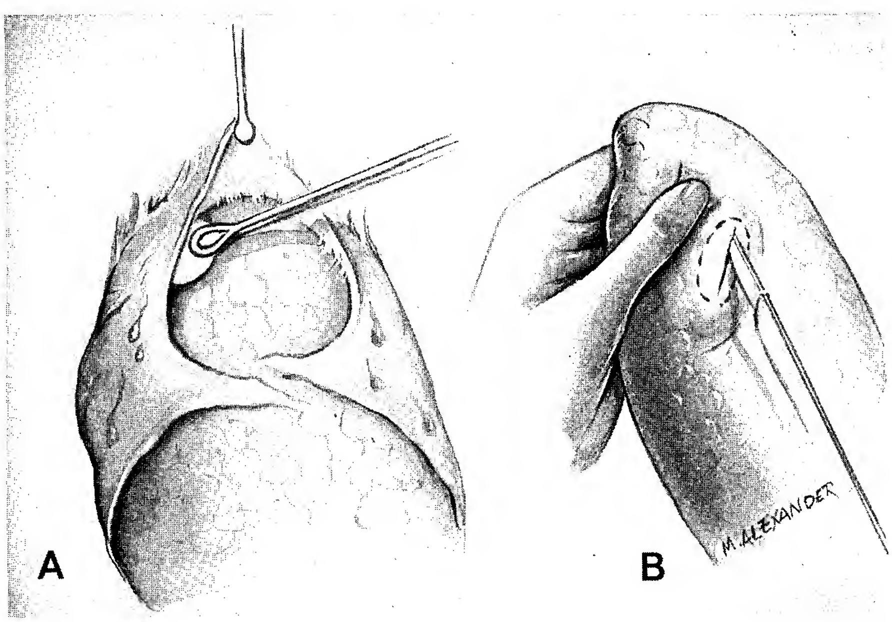

FIGURE 107.—Technique of decortication. A. Dissection of rind over upper lobe of lung. B. Lung incised over foreign body which has been fixed by finger compression.

of points of attachment between the visceral and parietal surfaces at the costophrenic fringe might not permit unfolding of the involved fringe if basal distortion was extensive. In such a case, there might also be a symphysis between the opposed diaphragmatic surfaces of the visceral pleura. The attachment of one visceral surface to another was usually much less firm than the attachment between visceral and parietal surfaces. The surgeon, therefore, could readily slip his finger into the groove. Here it would encounter an intrapleural tunnel, covered only by a veil of thin adhesions. Release of these adhesions permitted unfolding of the involved portion of the lung and restoration of its normal contour.

Complete reexpansion of the lung, with obliteration of intrapleural dead space, was the best possible insurance against a complicating empyema. Any compromise with this ideal was an invitation to failure. An operation that ended without bringing the lung into absolute contiguity with the chest wall and without making certain that it remained there had failed to achieve its purpose. It was a fallacy to assume that half measures in this direction would, by the generous intervention of Providence or something else equally unlikely, result in cure. Unless a complete operation was performed, the patient might be left in a situation only slightly more favorable than his original state.

Final steps.—When all of these procedures had been accomplished, the inner thoracic walls were carefully inspected and palpated, to be certain that their surfaces were perfectly smooth. Tags and cuffs of tissue were removed as they were encountered; they encouraged pocketing and the creation of dead space.

Two or three of the intercostal nerves above and below the incision were injected with procaine hydrochloride solution (1- or 2-percent). The pleural cavity was thoroughly lavaged with at least 1,000 cc. of physiologic salt solution and then was dried by aspiration. After it was certain that it was empty and that there were no bleeding points, the lung was brought gradually to complete expansion and then was tested again for air leaks.

Modifications of technique.—The technique just described was followed in most decortications. Some surgeons varied it in small details. Thus, some thought it essential to free that portion of the lung which, while not encased, was slightly adherent to the chest wall beneath the reflection of the peel to the surface of the parietal pleura or was adherent to the diaphragm and the mediastinum. An occasional surgeon removed all three elements forming the capsule of the pleural pocket; that is, the visceral, diaphragmatic, and parietal elements. When this technique was followed, the visceral element was completely removed before, by a return to the original incision, a plane of cleavage was found between the parietal element and the chest wall. The separation, which was quickly accomplished with the finger or a blunt instrument, was continued until the previous field of dissection was encountered along the line at which the visceral element was reflected onto the parietal pleura.

Drainage.—The sites for drainage were selected with the aim of obliterating dead space and maintaining pulmonary expansion. Soft rubber tubing, with an internal diameter of 10 mm., was used in all areas except the second interspace. Here, a de Pezzer catheter (No. 12 or No. 14) was used. The tip of the catheter was cut off, so that just the flange remained, and the tube was brought out anteriorly in the midclavicular line. A second drainage tube was used in the eighth interspace in the posterior axillary line. It was introduced for 2½ or 3 inches, and the proximal end was tacked to the parietal pleural wall, about 6 cm. from the skin surface, by a single silk suture. In infected hemothorax or empyema, a third tube was used in the fifth or sixth interspace in the midclavicular line, and a fourth tube was sometimes used in the seventh interspace in the midclavicular line.

If there had been a previous rib resection for drainage, the site of election for the posterior drainage tube usually corresponded with the site of previous drainage. In such cases, the margins of the wound were freshened, the tube introduced through it, and airtight closure accomplished about it. The drainage tube introduced at the first operation was sometimes removed 3 or 4 days before decortication, in anticipation of this procedure.

Closure.—Closure was accomplished in layers after the lung was completely within the chest. Sutures were placed in the inner layer of the incision but were not tied until the ribs had been approximated with lion-jawed forceps or retractors. Pericostal sutures were not used.

Local penicillin instillation.—Penicillin solution, in roughly equal amounts, was introduced into each drainage tube in infected cases. Each cubic centimeter of the solution contained 1,000 units of penicillin. The total amount used was from 25,000 to 50,000 units in 100 to 200 cc. of physiologic salt solution. All tubes were clamped when the patient left the operating room. The posterior tube was kept clamped for 4 to 6 hours, to permit contact between the penicillin and the tissues for this period of time. The other tubes were connected with water-seal bottles as soon as the patient was placed in bed.

POSTOPERATIVE MANAGEMENT AFTER DECORTICATION

General measures.—The postoperative management of a patient who had undergone pulmonary decortication was much the same as the regimen instituted after any other major thoracic operation. The reaction to operation was usually minimal, and the temperature and the pulse remained generally level in most cases (fig. 108). Even if empyema recurred, the temperature elevation was usually minimal.

Replacement therapy, in the form of blood, plasma, or dextrose infusions, was employed as necessary in each case. Return to a full diet, high in calories and protein, was usually possible within 24 hours after operation.

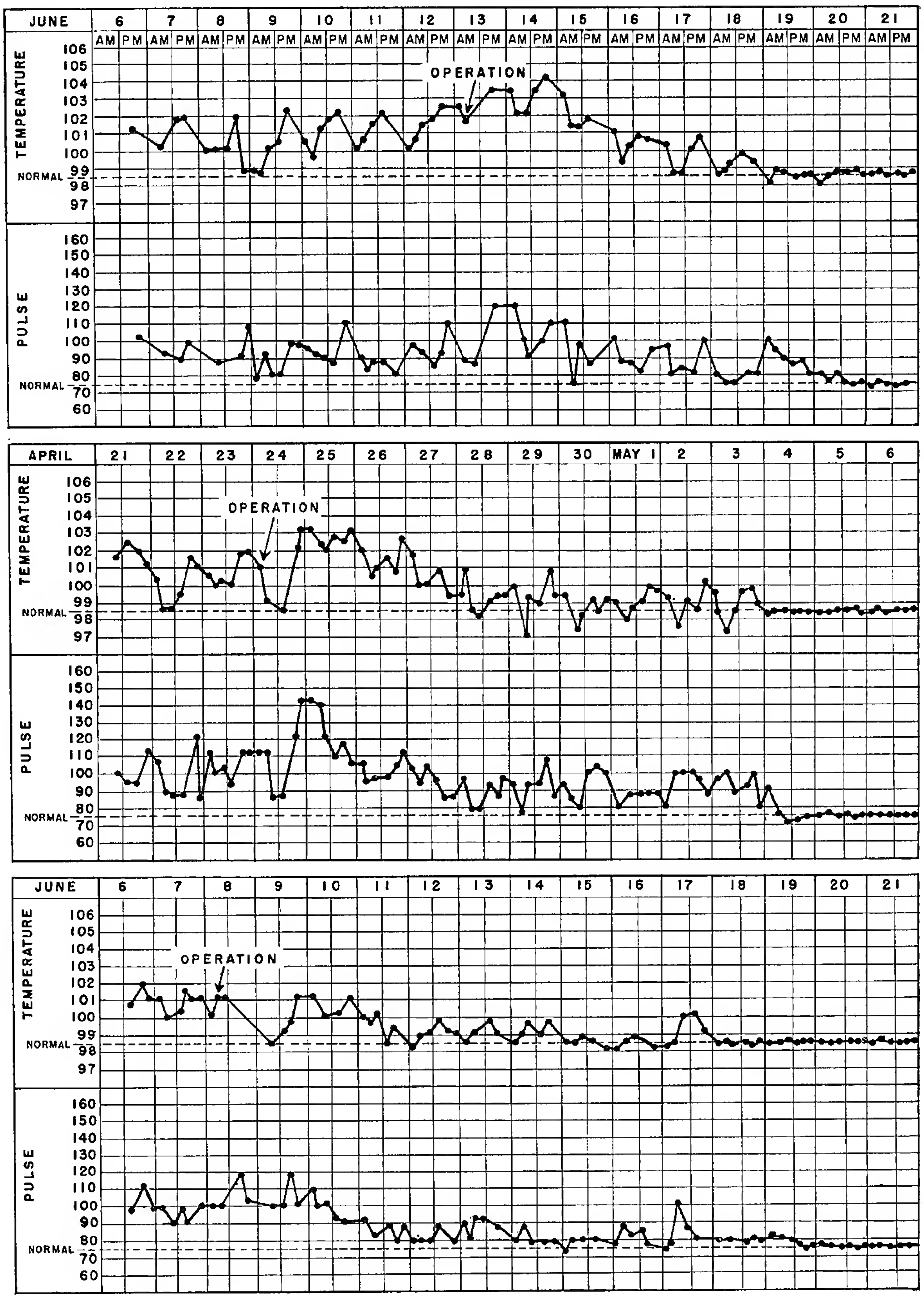

FIGURE 108.—Typical temperature charts of patients with hemothoracic empyema treated by primary decortication with penicillin coverage. Note absence of postoperative reaction and prompt defervescence in all cases.

As soon as he had fully reacted, the patient was elevated on a backrest, and the importance of deep breathing, forced expiration, and voluntary coughing, which had been explained to him before operation, was reiterated. These were all essential measures in the maintenance of pulmonary reexpansion.

Many surgeons regarded early ambulation as an important phase of the postoperative regimen. Some failures after decortication, in fact, were attributed to the immobility required by management of fractures of the extremities in traction. Thereafter, orthopedic surgeons were requested to manage these injuries in some way that would permit movement about the bed, at least.

Postural consciousness was stressed during the period of bed rest, and motion of the shoulder and arm was encouraged in the early postoperative period, before formal exercises were begun. Return to full activity was as rapid as was consistent with progress.

Penicillin therapy.—Intramuscular injections of penicillin were given by the dosage schedule used before operation until the drainage tubes had been removed and the patient had been afebrile for at least 2 or 3 days. This usually required that it be given for 10 to 14 days after operation.

Drainage.—The drainage tubes required close supervision. They were useful only as long as they functioned to maintain pulmonary reexpansion and to obliterate intrapleural dead space. They were essential for these purposes. Once these purposes had been achieved, the tubes simply acted as unnecessary foreign bodies. If the tubes had been placed correctly and hemostasis had been satisfactory, so that there was no undue oozing, it was only occasionally that any trouble was encountered in maintaining satisfactory drainage.

If a fistula developed, the anterior tube was kept in place as long as the air leak persisted, which might sometimes be as long as from 10 to 14 days. In none of these cases did intrapleural infection develop.

Complications.—Recovery was usually without incident, but fistulas and empyemas or recurrent empyemas were occasionally encountered. The low incidence of postoperative empyema was attributed both to good surgery and to penicillin protection.

If infection developed, as shown by a change from serous to purulent drainage, the postoperative empyema was usually basal and small. Dependent drainage was instituted at once. After a 2-inch resection of the eighth rib, a large airtight tube was inserted in the posterior axillary line and was attached to a water-seal bottle, to prevent secondary collapse of the lung.

DECORTICATION IN EMPYEMA OF NONTRAUMATIC ORIGIN

The experience with decortication in postpneumonic empyema in World War II was limited, one reason being (table 14) that the number of such cases was limited.

The rationale of the use of this operation in this variety of empyema was, however, entirely clear. If one compares the description of the histologic

appearance of the fibrinofibrous membrane in such cases in World War I (*2*), it is evident that there is little difference between it and the membrane observed in the posttraumatic empyemas of World War II. This similarity, together with the fact that, at least in the early stages of postpneumonic empyema, the pleura is essentially normal, suggested the use in World War II of decortication in early, carefully selected cases of subacute or impending chronic postpneumonic empyema. When the indication for surgery was total or subtotal empyema with collapse of the apex, loculation of the exudate was a further reason for considering decortication.

The thoracic surgeons who revived decortication in World War II believed that it would be technically possible to employ it in early or subacute tuberculous empyema, but their wartime experiences provided no opportunity to test the theory. It will be remembered that decortication had been originally used by Delorme (*10*) in 1893 for a "tuberculous" abscess of the chest wall with intrapleural extension (vol. I).

Although postpneumonic empyema was only a minor problem in World War II, enough of it was observed to evaluate the role of penicillin in its management during the acute stage. Observations at the various thoracic centers showed that this agent was a valuable adjunct, but that it did not take the place of adequate surgical drainage or, in the selected cases just mentioned, of decortication.

SPECIAL STUDIES OF PULMONARY DECORTICATION

Approximately 1,500 pulmonary decortications were performed in the Mediterranean and European theaters during World War II on the various indications outlined earlier in this chapter (p. 281). It is known that the surgical mortality rate was less than 2 percent. Lack of facilities and the general circumstances of wartime prevented a followup of these patients, but analyses of several series show that superior results were obtained. There was no doubt that decortication gave better results than methods used earlier. There was also no doubt that the results in primary decortication without drainage were much better than the results of secondary, postdrainage decortication (p. 310).

As already pointed out (p. 240), the incidence of empyema in the Mediterranean theater was far lower than even the most optimistic had dared to hope. The very favorable rate was the result of a totally integrated program of management of chest wounds that reflected credit on all echelons of medical care, particularly forward echelons.

The reduction in the incidence of posttraumatic empyema as the war progressed could not be attributed to any single therapeutic advance. Instead, it was due to a combination of improvements. The most important of these was the increasing emphasis put upon adequate debridement of chest wounds and

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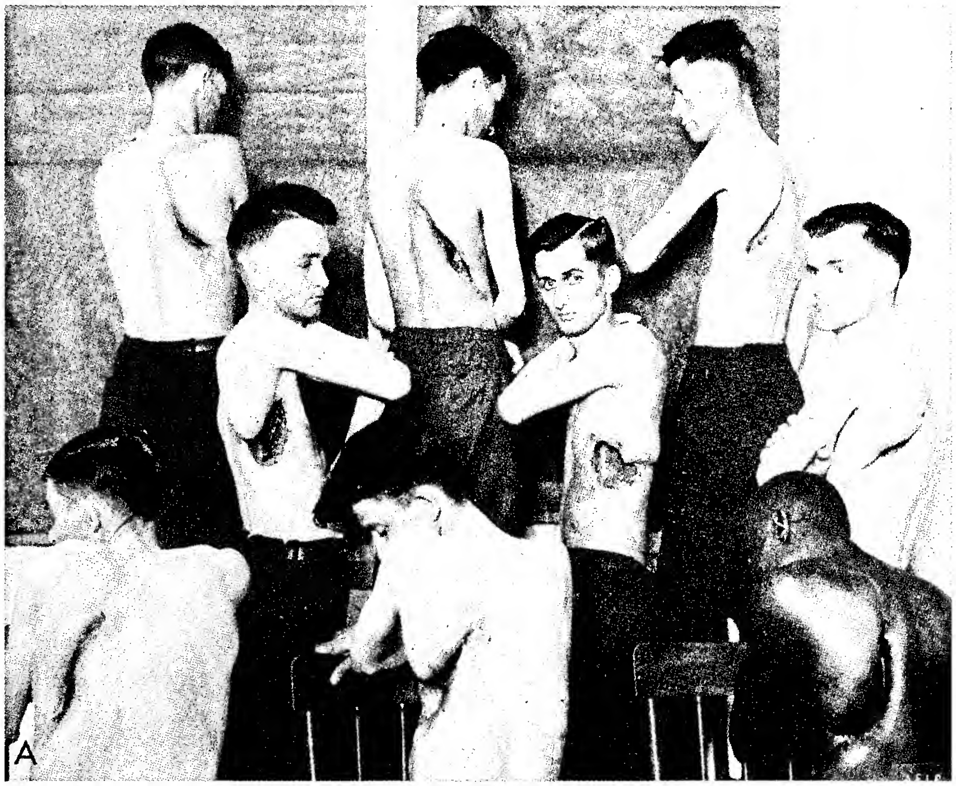

FIGURE 109.—Comparative results of management of empyema in World Wars I and II. A. Typical patients with chronic empyema in Zone of Interior hospitals in World War I (2).

upon early, rapid, vigorous evacuation of the pleural cavity and prompt reexpansion of the lung. Another extremely important consideration was the decrease in the number of ill-advised thoracotomies in forward areas. The acceptance of the concept that a hemothorax is for all practical purposes a hematoma carried with it an implied warning as to how to avoid pleural sepsis, a warning that eventually was widely heeded. Fewer and fewer hemothoraces that required multiple aspirations were encountered in base hospitals in the last year of the war. The use of pencillin in forward areas no doubt favorably influenced the empyema statistics, but good surgery was the chief explanation of the improvement.

In base hospitals, the proper management of large clotted hemothoraces further tended to reduce significantly the incidence of empyema. The prophylaxis of chronic empyema was, in fact, one of the most important functions of a chest center. Early pulmonary decortication was of great value in accomplishing this purpose as well as in curing empyema that had become established.

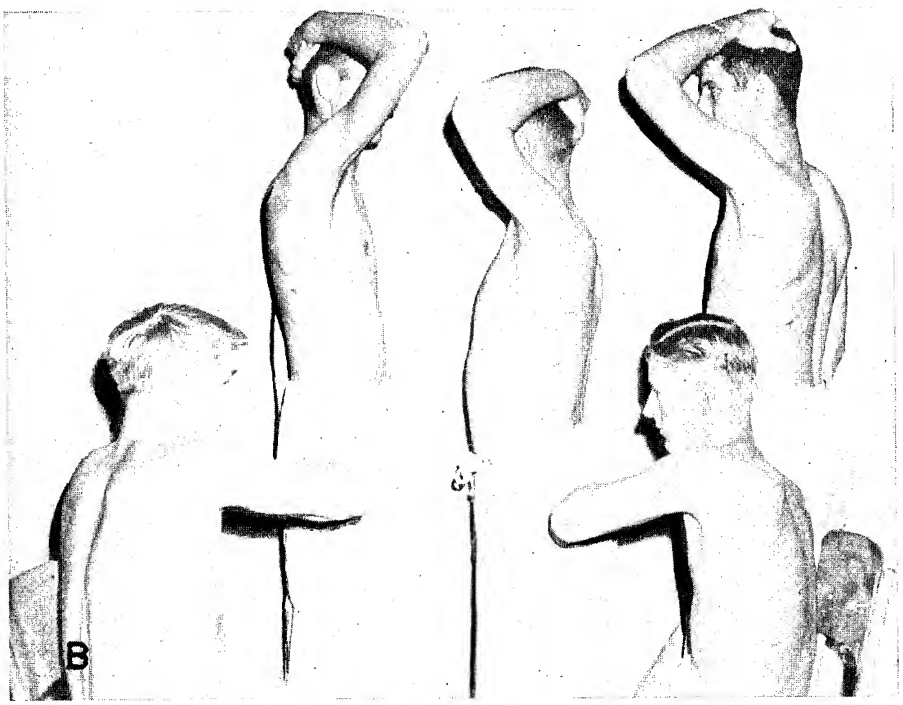

FIGURE 109.—Continued. B. Typical World War II casualties after primary decortication for posttraumatic empyema. In each of these cases, recovery was without complications, and patients were left with no residual disabilities.

The most striking and most convincing evidence of the value of decortication was the almost total elimination of the group of unfortunate victims of World War I (fig. 109A) who spent the post bellum years doggedly undergoing one major surgical procedure after another or living through a shortened lifespan of chronic invalidism due to recurrent episodes of suppuration. Many of the casualties treated by decortication in World War II (fig. 109B) were sent back to full duty, and a considerable saving in human suffering as well as in military manpower was thus effected.

Criteria of cure.—Several criteria of cure were set up in decortication for organizing hemothorax, infected hemothorax, and hemothoracic empyema:

1. The lung must be fully expanded at operation or within 2 weeks thereafter and the pleural cavity must be completely obliterated within 2 weeks of operation, as demonstrated by roentgenologic evidence (figs. 110, 111, 112, and 113) and by cessation of fluctuation in the water-seal drainage apparatus.
2. There must be no clinical or roentgenologic evidence of occurrence, persistence, or recurrence of empyema during the period of postoperative observation, which ranged from 4 to 12 weeks.
3. There must be no evidence of embolic spread of infection.

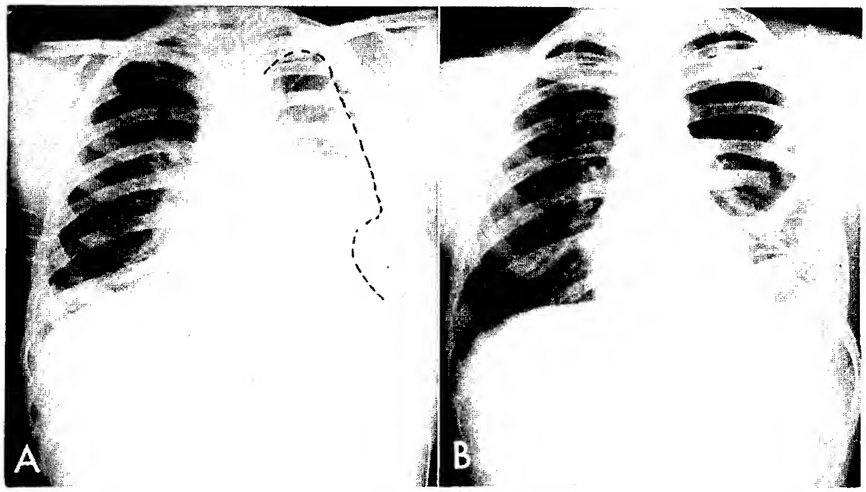

FIGURE 110.—Management of hemothorax by secondary decortication. A. Posteroanterior roentgenogram showing massive liquid hemothorax on left before operation. Treatment by rib-resection drainage had been ineffective. B. Same, 4 weeks after decortication. Primary cure occurred.

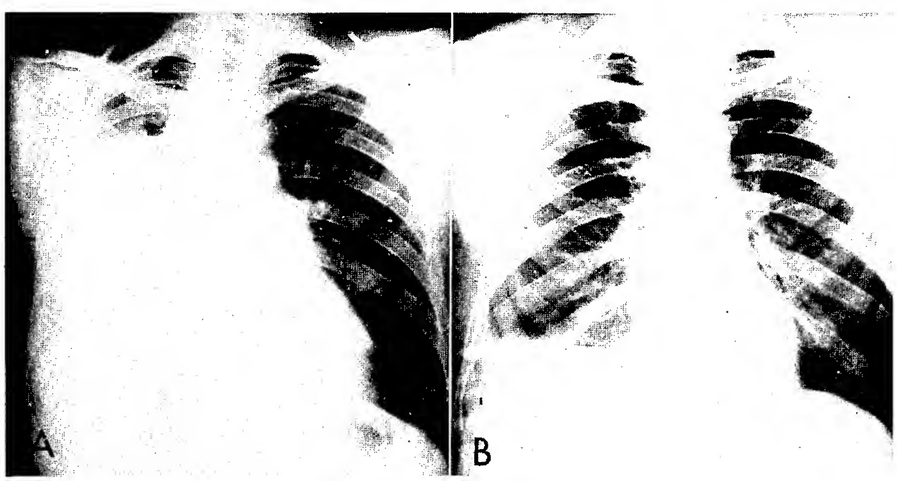

FIGURE 111.—Management of hemothoracic empyema by primary decortication. A. Posteroanterior roentgenogram showing massive clotted right-sided empyema before operation. B. Same, showing practically normal chest 3 weeks after primary decortication.

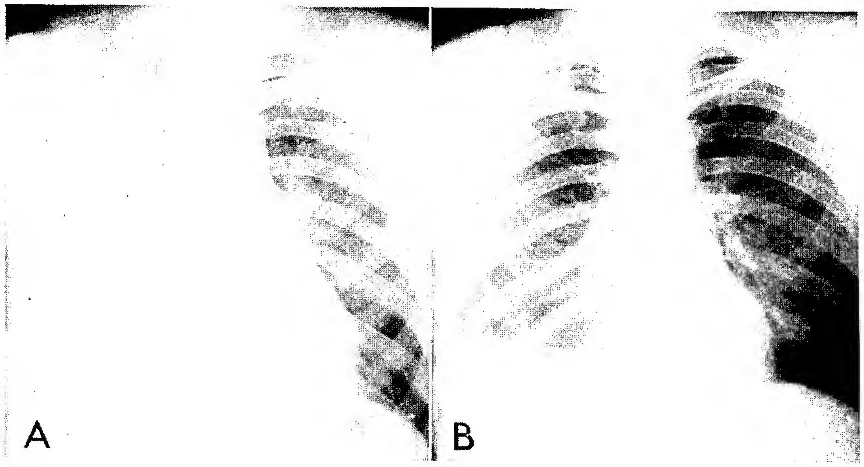

FIGURE 112.—Management of hemothoracic empyema by decortication. A. Posteroanterior roentgenogram showing early massive hemothoracic empyema just before operation. B. Same, 2 weeks after primary decortication. Note that lung has completely reexpanded and there is no evidence of residual empyema.

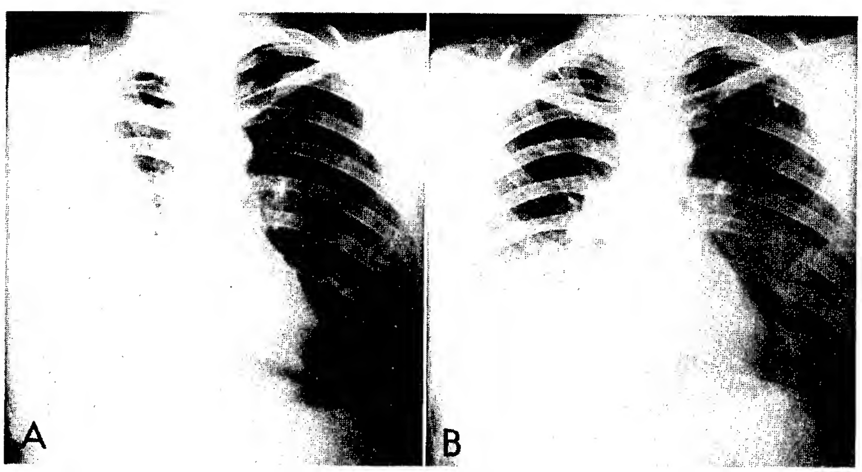

FIGURE 113.—Management of clotted hemothorax by primary decortication. A. Posteroanterior roentgenogram showing large clotted hemothorax on right. B. Same, 3 weeks after decortication. Complete cure resulted.

Earliest Operations

An analysis of the first 25 decortications performed in North Africa, all by surgeons of the 2d Auxiliary Surgical Group, showed that all the patients were seriously ill and that the outlook in many of them was distinctly unfavorable. The single death in the series occurred 8 weeks after operation and was not related to it. In spite of the gloomy prognosis, there were 18 primary cures. In every instance, the temperature and the pulse returned to normal levels within 7 to 10 days after operation and there they remained. At the same time, there was a striking improvement in every patient in general appearance, in appetite and nutrition, in a rapidly restored sense of well-being, and in the capacity for a resumption of essentially normal activity.

One of the five recurrent empyemas was explained, at least in part, by the fact that the patient was treated in traction for a fractured femur and was almost completely immobile throughout the postoperative course. In the other four patients with empyema, the original cavities were greatly reduced in size and became progressively smaller during the period of observation after operation.

Of the 24 survivors, 2 were returned to full duty and 7 to limited duty in the theater, with the recommendation that their status be reviewed within 90 days. The other 15 were evacuated to the Zone of Interior, 5 because of recurrent empyema and 2 because of concomitant wounds. All were in good condition when they left the theater.

Decortication at the 21st and 300th General Hospitals

An analysis of 125 decortications performed at the 21st and 300th General Hospitals in the Mediterranean theater, between 1 April and 20 December 1944, showed no surgical deaths and only one complete failure in one of the earliest cases. There were no instances of invasive infection, and the only two wound infections were superficial.

Primary healing, with complete pulmonary restoration, occurred in over 90 percent of the cases in which the lung was normal at operation. The same results were accomplished in just over 75 percent of the group in which intrapleural infection had been present before operation. On the other hand, when the lung was involved in the original pathologic process, empyema was recurrent in 40 percent of the cases. Practically all of the recurrent empyemas, however, were basal and small, and they therefore responded well to rib resection and drainage. It seems fair to say that, with the exception of the single complete failure, all the patients in this series who did not obtain a primary cure at least benefited materially from decortication.

Decortication at the 12th and 36th General Hospitals

In a followup study of 140 of the 160 decortications performed at the 12th and 36th General Hospitals in the Mediterranean theater, Maj. William M.

Tuttle, MC, Capt. (later Maj.) Hiram T. Langston, MC, and Maj. Robert T. Crowley, MC, published the following data:

There were no deaths in the 140 patients followed up, and, so far as could be determined, there were no deaths in the 20 not followed up.

In the 140 patients followed up, the hemothorax was organized but not grossly infected in 89. In all of the other 51 cases, infection either was known to be present before operation or was encountered unexpectedly at operation. In 90 percent of the total (160) series, the intrapleural mass exceeded 1,000 cc. in volume.

In 90 of the 140 patients followed up, pulmonary reexpansion was complete within the first 24 hours, and in 18 others, it was complete within the next 24 hours. Twenty-six patients required 72 hours or more for complete reexpansion, and in the 6 remaining patients, the results from this standpoint were not satisfactory.

Of the 89 patients with organizing uninfected hemothoraces, 8 developed empyema after decortication. Most of the infections were merely small pockets that responded readily to drainage. All were either completely healed when the patients were evacuated or were progressing so favorably that it was thought that no further surgery would be necessary.

Recovery was without incident in 25 of the 51 patients who had grossly infected hemothoraces before operation. In 23 cases, small residual empyemas recurred, ranging in volume from 30 to 200 cubic centimeters. These pockets, as in the group just described, were either completely obliterated before the patients were evacuated or were progressing so satisfactorily that no further surgery seemed likely to be required. In the three remaining cases, additional surgery seemed inevitable.

The only other complications in the series were two wound infections. Although both patients had had preoperative empyema caused by *Clostridium welchii*, neither infection was severe. The absence of serious wound infections in this series is rather remarkable when it is recalled that many of the operations lasted from 1 to 3 hours and that the infected material traversed the wound during most of this time.

Penicillin became available while the operations in this series were in progress and was used in 77 cases. They are not consecutive; even when restrictions on its use were removed, it was employed only on indications. Of the eight patients who developed empyema after decortication of a presumably uninfected organizing hemothorax, five received penicillin during the immediate postoperative period and three did not. All 25 patients who recovered uneventfully after decortication performed in the presence of infection received it, which suggests the value of this form of therapy. Sulfonamides were not used in any case in the series.

The duty status of 3 of the 140 patients was not known when the report was made. Six were returned to full duty and 64 to limited duty in the theater, in a number of instances with the recommendation that their status be reviewed

in 90 days. Twenty-three other men could have been returned to duty in the theater as far as their thoracic wounds were concerned, but associated wounds made this impossible. The remaining 44 patients had to be evacuated to the Zone of Interior because of the severity of their chest wounds.

Comparative Results of Rib-Resection Drainage and Decortication

An analysis of 94 cases of hemothoracic empyema treated by surgeons of the 2d Auxiliary Surgical Group after the indications for decortication had been stabilized permits a comparison of the results obtained in hemothoracic empyema by rib-resection drainage, primary decortication, and secondary decortication.

Rib resection was the method of treatment in 72 cases, in 6 of which secondary decortication was necessary later. The other 22 patients were treated by primary decortication.

Rib-resection drainage.—Excluding the 6 cases in which rib-resection drainage was followed by secondary decortication and which will be discussed separately (p. 310), 66 patients, 5 of whom died, were treated by rib-resection drainage.

Of the 66 patients, 59 had small or moderately large empyemas, many of them basal. The majority still had small residual cavities when they were evacuated to the Zone of Interior, but progressive obliteration had occurred, and it was not thought that any of the patients would require further surgery.

The other seven patients had massive infections, and primary decortication would have been the treatment of choice had their condition permitted it. In some cases, their serious status was due to associated wounds rather than to empyema. Satisfactory pulmonary reexpansion occurred in only four of the seven cases.

In one of the three failures, a large fistula in the right main bronchus opened into a persistent large empyema cavity. The fistula would ordinarily have been closed and secondary decortication performed, but an associated laceration of the dorsal spine, with paraplegia, made the prognosis hopeless. In the two remaining cases, exploratory thoracotomy was carried out, in the hope that decortication could be done, but in both, the infectious process was already chronic, and operation was not considered feasible. All three patients were evacuated to the Zone of Interior, with recommendations for later surgery.

One of the 5 deaths in the 66 patients treated by rib-resection drainage was caused by a metastatic brain abscess, which is one of the hazards of empyema treated by this method. Two deaths were due to overwhelming pleural infection secondary to esophagopleural fistulas, and two were due, in large part, to severe associated wounds.

Primary decortication.—All 22 patients who underwent primary decortication had massive involvement of the pleural cavity, 4 on the basis of liquid hemothoraces and 18 on the basis of clotted hemothoraces.

In a few instances, decortication had to be deferred longer than was considered desirable because of the gravity of associated extrathoracic wounds. In one case, the delay was 63 days. One or two patients did not come under observation until more than a month after wounding. Excluding these patients, the timelag between wounding and decortication ranged from 7 to 31 days and averaged 20 days. This timelag included a purposeful delay of 2 to 4 days after the diagnosis of empyema was made, to prepare the patients for operation.

The results in these 22 decortications were as follows:

A prompt cure was obtained in 18 cases, in 16 of which the empyema had originated in clotted hemothoraces. Included in these 18 cured patients were 2 who had small lung abscesses, each of which was associated with a foreign body and a bronchopleural fistula at the site of the abscess. In each instance, the foreign body was removed at decortication, the walls of the abscess excised, and the residual defect, including the fistula, closed in layers. There were no postoperative complications in either case.

In the four remaining cases in which primary decortication was done, there was a postoperative recurrence of empyema. All four patients were then treated by rib-resection drainage, with the following results:

In two cases, the recurrent cavity was small, and in both instances, it was almost completely obliterated when the patients were evacuated to the Zone of Interior. One of these patients had a late bronchopleural fistula, which closed spontaneously. It was not thought that additional surgery would be necessary in either instance. Why the empyema recurred in these two cases is not clear, for in both, complete expansion of the lung was obtained at operation.

In the third case, the cause of the recurrence was readily apparent. A large lung abscess was found at operation, surrounding a large foreign body and also the site of a bronchopleural fistula. To excise the abscess completely would have required lobectomy, and the patient's condition was too critical for such radical surgery. The fistula was closed, but the infection was not eliminated, and recurrence was regarded as inevitable. The recurrent cavity was small, but the closure of the fistula broke down, and further surgery would be necessary in the Zone of Interior.

In the fourth case, the cause of the recurrence was also apparent. This patient had a large lung abscess. It involved almost half of the lower and middle lobes on the right side and was also the site of a bronchopleural fistula. Partial lobectomy was performed on each of the affected lobes, and the fistula was closed. The remaining lung reexpanded normally after decortication, but the recurrence was expected because of the large amount of dead space left after lobectomy. Both the original and the recurrent infections were caused by *Escherichia coli*. The patient was seriously ill, and it was debatable, before the first operation, whether primary decortication or rib-resection drainage should be performed. He did not improve after decortication and lobectomy, and death occurred on the 30th postoperative day, from persistent and overwhelming

intrapleural infection. There was no response to either penicillin or the sulfonamides. This was the only death in the 28 patients treated by decortication.

Secondary decortication.—In all six cases in which secondary decortication was employed after rib-resection drainage, the operation would have been done primarily had the patient's condition permitted it; in three cases, drainage was done for empyema necessitatis. In five of the six cases, the empyema had developed in liquid hemothoraces.

In all six cases, although drainage was apparently adequate, there was either no reexpansion, or only unsatisfactory reexpansion, of the lung, and decortication was resorted to because chronic empyema seemed to be impending. The duration of drainage before decortication ranged from 26 to 53 days and averaged 37 days. The timelag from wounding to the secondary operation ranged from 44 to 64 days and averaged 52 days.

The outcome in these six cases shows again that primary decortication gives better results than the secondary operation. Prompt recovery ensued in two cases, but empyema recurred in the other four. On the other hand, these four operations cannot be considered total failures. They were performed because there was no significant pulmonary reexpansion, in spite of adequate drainage, and because in each instance more than 50 percent of the lung was collapsed. Even though the empyema recurred, it was thought that the purpose of decortication had been accomplished: In two cases, chronic empyema was positively prevented, and the anticipated duration of continued pleural suppuration was materially reduced. In the other two cases, while the situation was improved, it was thought that additional surgery would be necessary.

Conclusions.—The results obtained with decortication in these various series might be compared with the results reported by Nicholson and Scadding (*11*) in 291 wounds of the chest treated in British hospitals in the Middle East between November 1941 and May 1943, before decortication came into use. Hemothorax became evident in 187 cases and became infected in a third of these. The case fatality rate in 52 infected hemothoraces uncomplicated by pulmonary or subphrenic suppuration and managed by standard conservative measures was almost 20 percent, while at the time of the report, only 12 of the surviving patients were known to be entirely well.

Two points concerning the advantages of decortication over drainage operations for organizing hemothorax and hemothoracic empyema, although they have been made before, should be stressed again:

1. In favor of decortication was the short interval, usually from 6 to 8 weeks, necessary to effect a cure, compared with the weeks of suppuration, changes of drainage tubes, and daily dressings necessary in other methods. With their wounds cleanly and solidly healed, and their lungs fully expanded, the patients were well on the way to recovery within 2 to 3 weeks after operation.

2. In pleural infections treated by drainage, the road from the institution of drainage to a complete cure was not only long, it was also beset with dan-

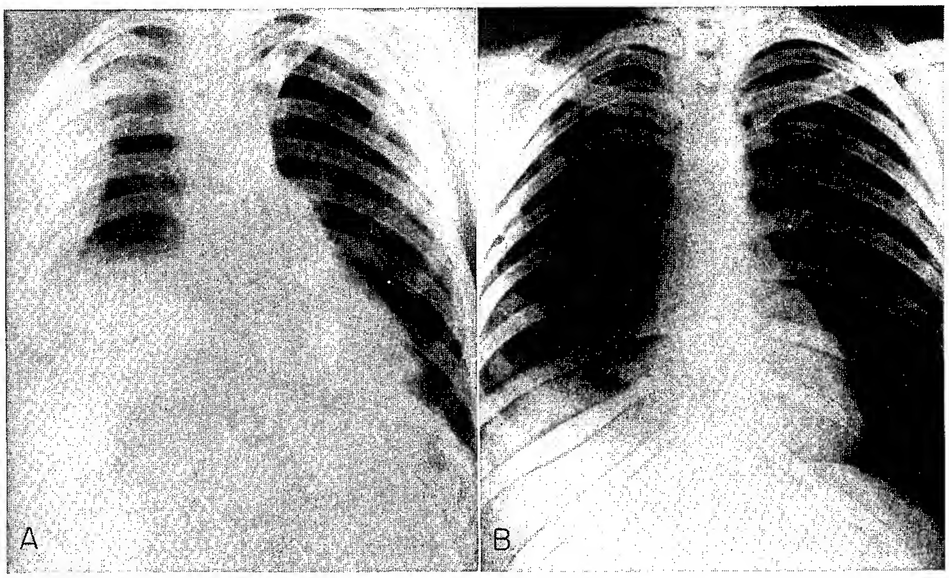

FIGURE 114 (case 1).—Spontaneous clearing of clotted hemothorax. A. Posteroanterior roentgenogram showing clotted hemothorax of moderate size, without infection, 2 weeks after injury. B. Same, 1 month later. Chest was almost completely cleared without surgery or additional thoracenteses.

gerous pitfalls. Chronicity might eventuate at any stage, and death might occur from a number of causes, including metastatic brain abscess. With this method, the outcome was uncertain as long as a vestige of the empyema cavity remained.

CASE HISTORIES

Case 1.—A soldier who sustained a perforating gunshot wound of the right hemithorax on 14 June 1944, with a laceration of the right lung, developed a hemothorax of considerable size. The wounds were debrided, and a sucking wound of exit was closed. A flapper valve intercostal tube was inserted after 800 cc. of blood had been removed from the chest by thoracentesis.

Drainage was unsatisfactory, and the tube was removed 48 hours after wounding. Roentgenograms 14 days after injury showed a moderately large, clotted right hemothorax (fig. 114A). There was no evidence of intrapleural infection.

Repeated aspirations yielded only a few cubic centimeters of serum and fragments of clot, but, because of the moderate size of the hemothorax and the absence of any evidence of intrapleural infection, spontaneous clearing was allowed to progress. Recovery was smooth, and within 6 weeks after wounding the chest was almost clear (fig. 114B). The soldier was returned to duty on 17 August 1944, 2 months after he had been injured.

Comment.—This case illustrates the successful outcome of a hemothorax of moderate size, without infection, treated conservatively. Clotting occurred in spite of the prompt removal of blood by aspiration.

Case 2.—When this soldier was wounded in action on 6 February 1944, he sustained a severe penetrating wound of the left thorax, with a laceration of the left lung. Initial

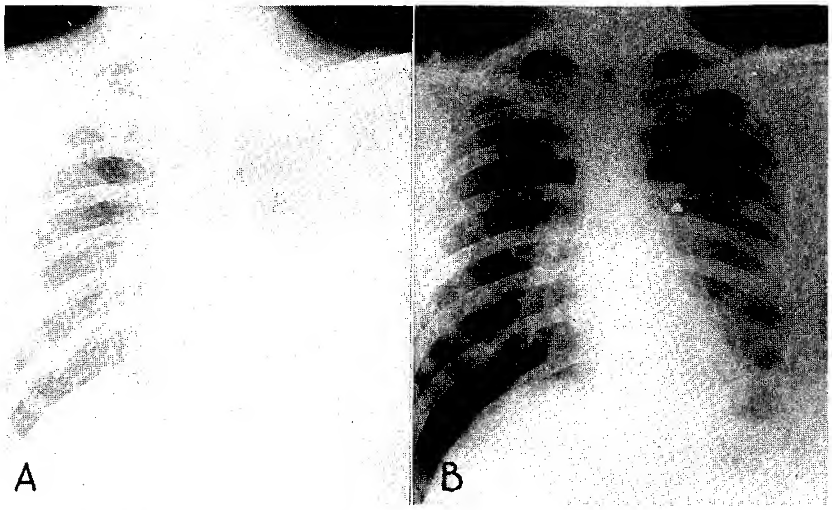

FIGURE 115 (case 2).—Management of clotted hemothorax by decortication. A. Posteroanterior roentgenogram showing massive clotted hemothorax, without infection, but with no tendency toward clearing after 6 weeks. Repeated thoracenteses were not effective. B. Same, 10 days after primary decortication. This patient went on to complete cure and was returned to duty. Foreign body was in chest wall.

therapy consisted of debridement of the wound and left thoracentesis. A metallic foreign body in the chest wall was left in situ.

Repeated thoracenteses were ineffective. Only small amounts of serum and fragments of clot could be obtained. Roentgenograms (fig. 115A) showed persistence of pleural fluid, with no evidence of resorption after 6 weeks. Thoracotomy with pulmonary decortication was then performed. A complete cure was obtained (fig. 115B), and the soldier returned to duty 3½ months after wounding.

Comment.—On the surface, there seems little difference originally between this case and the case just described (case 1). In both, clotting occurred, and additional aspirations were unsuccessful. Conservative treatment was practiced in both, with practically complete resolution at the end of 6 weeks in the first case, while in the second, no tendency toward resolution was evident. Decortication produced highly satisfactory results, and might, perhaps, have been employed earlier. If no tendency toward clearing was observed at the end of the third week after wounding, it was the general experience that it was unlikely to occur.

Case 3.—This soldier sustained a shell-fragment wound of the right chest on 31 May 1944. He had a sucking wound, a laceration of the lung, and a hemopneumothorax, all on the right side. Thoracotomy was performed in a forward hospital, with removal of the shell fragment in the lung, suture of the lung, and evacuation of the blood in the right pleural cavity.

When the patient was admitted to a chest center 11 days after wounding, he was desperately ill from massive empyema. The thoracotomy incision was reopened and the empyema drained through the bed of the rib that had been resected at initial wound surgery.

Drainage was apparently adequate, but the lung did not reexpand satisfactorily, and chronic empyema was evidently impending. Decortication was therefore performed 6 weeks

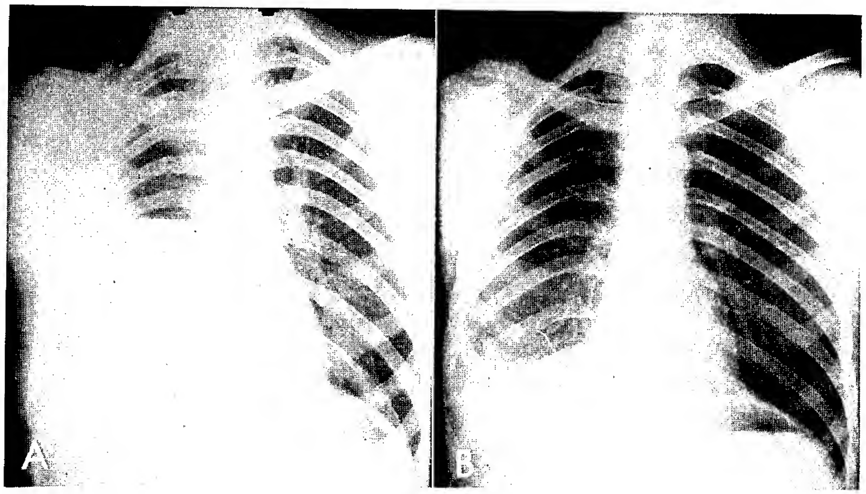

FIGURE 116 (case 4).—Management of hemothoracic empyema by primary decortication. A. Posteroanterior roentgenogram showing right-sided hydropneumothorax, with 50-percent compression of lung. Fluid component secured by aspiration soon became thick and purulent. Ninth rib had been partly resected when thoracotomy was done immediately after wounding in forward hospital. B. Same, 2 weeks after decortication. Regeneration is evident in this roentgenogram. Complete cure was obtained, with total pulmonary reexpansion and total obliteration of empyema cavity.

after the drainage operation. The lung was freed without difficulty from the fibrinofibrous membrane which encased it. As soon as this was accomplished, reexpansion was entirely satisfactory. Convalescence was without incident, and the end result was excellent.

Comment.—This patient was far too ill for such a major procedure as decortication when he was seen in the chest center 11 days after wounding. Rib-resection drainage was lifesaving, but it was not sufficient to accomplish a cure. In World War I, this soldier would have become a chest cripple. Decortication saved him from this fate in World War II. Whether the thoracotomy performed at initial wound surgery was necessary is at least debatable. He might have been better off without it.

Case 4.—This soldier, who was wounded in action on 4 June 1944, suffered a severe penetrating shell-fragment wound of the right thorax, with a laceration of the right lung and right hemopneumothorax. A foreign body was seen in the lung. Thoracotomy was performed at a forward hospital on the day of injury. The foreign body was removed and the pulmonary laceration sutured.

The immediate convalescence was uneventful, but a few days after operation, a clotted hemothorax was found on the right side (fig. 116A). The patient was toxic, and his temperature rose daily to 101° or 102° F. Purulent fluid was eventually recovered from the chest, and *Staphylococcus aureus* was cultured from it. Thoracotomy and decortication were done at once, without preliminary drainage. Recovery was uneventful, and the end result was excellent (fig. 116B).

Comment.—This is another case in which prompt decortication saved the casualty from a long period of drainage and disability, and perhaps from chronic invalidism. It is also another case in which the patient might have done better without thoracotomy as part of the initial wound surgery.

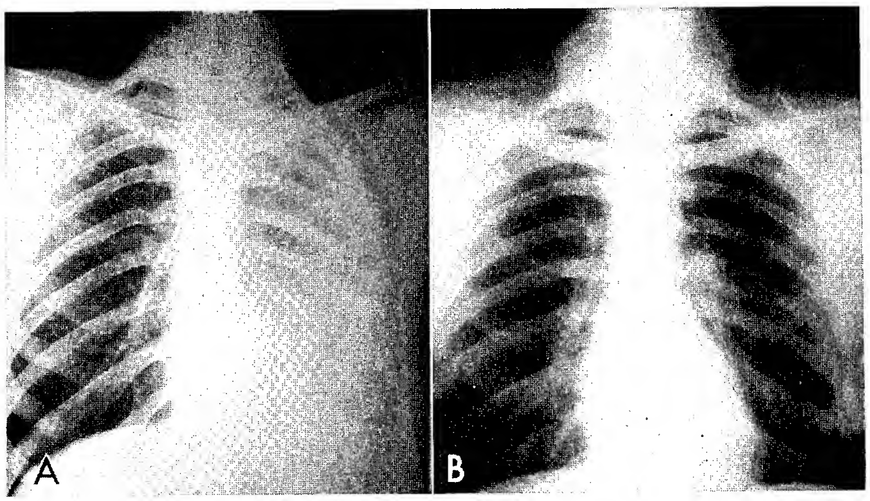

FIGURE 117 (case 5).—Management of clotted hemothorax by primary decortication. A. Posteroanterior roentgenogram 33 days after wounding, showing diffuse left-sided obscuration and narrowing of intercostal spaces caused by organizing clotted hemothorax. Thoracenteses had been ineffective. B. Same, 5½ months after primary decortication, showing essentially normal left hemithorax.

Case 5.—A 27-year-old soldier sustained an accidental sucking wound of the left anterior thorax during bayonet practice on 11 June 1943. A tension hemopneumothorax was managed by water-seal drainage for 48 hours. The sucking wound was trimmed and closed. Repeated thoracenteses produced no fluid.

When the patient was admitted to a thoracic surgery service on 10 July, the left chest was flattened anteriorly, and there was a slight scoliosis concave to the left. Expansion was appreciably limited. Horizontal expansion measurements showed the following differentials: Ensiform cartilage to spine on right, 1½ inches, on left ⅝ inch; nipple to spine on right, 1 inch, on left ¼ inch. Breath sounds were distant over the entire left chest.

For the past 2 weeks, the patient had been complaining of increasing dyspnea on exertion. He was now incapacitated for any activity except the most minor exercise, and he was showing no appreciable improvement.

Analysis of serial roentgenograms showed a persistent diffuse obscuration on the left, with the greatest density at the base. The roentgenogram taken on 14 July (fig. 117A) showed diffuse clouding. The intercostal spaces were narrowed, and there was a slight scoliosis concave to the left. There had been no essential change in these findings for the preceding 2 weeks.

On 16 July 1943, 35 days after injury, thoracotomy and decortication were performed. More than 500 cc. of clotted, degenerating blood was found occupying the space in the left hemithorax from the apex to the base and forward to the midaxillary line. The peel adherent to the visceral pleura was 3 mm. thick, and that adherent to the parietal pleura, which was left in situ, was 5 mm. thick. After decortication had been accomplished, there was immediate and almost complete reexpansion of the lung under slight positive pressure. A few bubbles of air escaped from a small tear in the visceral pleura, which was easily repaired.

Under the microscope, the visceral layer of rind showed adult fibrous tissue, with many penetrating capillaries, which were larger and more numerous on the visceral pleural surface.

Frequent thoracenteses were carried out for the next 5 days. Roentgenograms 20 days after operation showed a small residual lateral pneumothorax, with complete pulmonary reexpansion at the base. Measurements taken 30 days after operation showed the horizontal expansion from the ensiform cartilage to the spine to be 1¾ inches on the right and 1½ inches on the left. Expansion from the horizontal nipple to the spine was 1 inch on each side.

The patient was discharged to limited duty 60 days after operation. A followup roentgenogram on 6 January 1944 (fig. 117B) showed the left thorax to be essentially normal.

Comment.—In this case, clotting apparently occurred almost immediately, for prompt and repeated thoracenteses produced no fluid. The patient was well on his way to becoming a chest invalid when thoracotomy and decortication were performed. As this case shows, the risks of removing the thicker and more vascular parietal peel need not be taken. It was left in situ at operation, and the patient made an excellent recovery. Repeated thoracenteses were employed after operation because drainage had been omitted.

Case 6.—A 19-year-old German prisoner of war sustained perforating wounds of the left chest from a high explosive shell fragment. The small wound of entry was located in the second interspace in the midclavicular line and the slightly larger wound of exit, in the eighth interspace in the midscapular line. Neither was sucking.

The wounds were debrided 24 hours after injury. At this time, roentgenograms revealed a left-sided hemothorax that was causing approximately 45-percent collapse of the lung. No fluid was obtained on thoracentesis.

For the next 8 days, the patient ran a febrile course, the temperature on one occasion reaching 103.2° F. Repeated aspirations during this period yielded only fragments of clot and shreds of fibrin. Smears and cultures were negative.

A roentgenogram 9 days after injury (fig. 118) showed the left hemithorax obscured and the lung compressed. The following day, a catheter (No. 22) was inserted into the left pleural cavity, but neither fluid nor clot could be evacuated.

Because of the continued fever and toxicity, it seemed probable, in spite of consistently negative cultures, that infection was developing in an organizing hemothorax. Thoracotomy and decortication were therefore performed 14 days after wounding. The pleural cavity was filled with clots and with loculated pools of thick, sirupy blood. The hemothorax was, as usual, larger than the roentgenograms had indicated. The lung was held immobile by a 2-mm. peel of fibrin, which was undergoing early organization. Decortication was technically tedious and difficult because of the thinness and friability of the peel. It stripped easily, but piecemeal removal was necessary. The underlying visceral pleura was grossly normal and did not bleed. No attempt was made to decorticate the parietal pleura. The wounds of entrance and exit in the upper lobe were solidly healed, and the fibrin peel over both areas was left undisturbed. When the diaphragm was freed, it immediately resumed its normal excursion. Before decortication, positive pressure up to 15 cm. H_2O did not result in any pulmonary expansion. After decortication, the lung expanded promptly and filled the hemithorax.

Drainage was instituted through two intercostal tubes. The anterior tube was removed at the end of 24 hours and the posterior tube on the third day. The patient then became ambulatory. Roentgenograms on the seventh day after operation showed complete pulmonary reexpansion. When the patient was evacuated to a prisoner-of-war camp on the 14th day after operation, he was in excellent condition.

Cultures of the clot and peel removed at decortication were negative on both aerobic and anaerobic media.

Comment.—This case is an illustration of the prophylactic use of decortication. Obviously, infection was impending in an organizing hemothorax, and while the operation is somewhat more difficult as early as 14 days after wounding, because the rind is not yet well organized, it can be safely performed.

FIGURE 118 (case 6).—Posteroanterior roentgenogram showing organizing clotted hemothorax on left side. Note apical compression and almost 50-percent pulmonary collapse.

Case 7.—A 34-year-old soldier sustained a sucking wound of the right posterior thorax on 23 September 1943. The wound was closed immediately by an occlusive dressing, and 24 hours later, primary closure of the pleura was performed. Water-seal drainage was continued for the next 48 hours.

On 27 September, 1,800 cc. of air and fluid were aspirated from the right hemithorax. The following day, roentgenograms (fig. 119A) showed a large amount of blood in the right pleural cavity, with a 75-percent collapse of the lung. On 30 September, 100 cc. of bloody fluid was aspirated, with considerable difficulty. A second attempt to evacuate the chest with intercostal water-seal drainage produced only 200 cc. of bloody fluid in 24 hours. On 5 October, all that could be obtained on aspiration was 20 cc. of sterile fluid. At this time, a lateral roentgenogram (fig. 119B) showed extensive obscuration at the base and multiple fluid levels, characteristic of intrapleural infection. The patient continued toxic and febrile.

On 7 October, right-sided posterior thoracotomy was performed after two small granulating wounds of the right posterior chest wall had been excised and closed with a separate set of instruments. Short posterior segments of the seventh and eighth ribs were removed, and the pleural cavity was entered through the seventh intercostal space. The lung was found bound down with characteristic organizing exudate and approximately 90 percent collapsed. The pleural cavity was filled with liquid blood, serum, masses of fibrin, and blood clot in various stages of degeneration.

When the peel was removed from the visceral pleura, there was immediate and almost complete reexpansion of the lung under slight positive pressure. The lacerations at the sites of the through-and-through pulmonary wounds were repaired with fine silk. Drainage was instituted. Immediate bronchoscopy was productive of a moderate amount of bloody mucoid secretion.

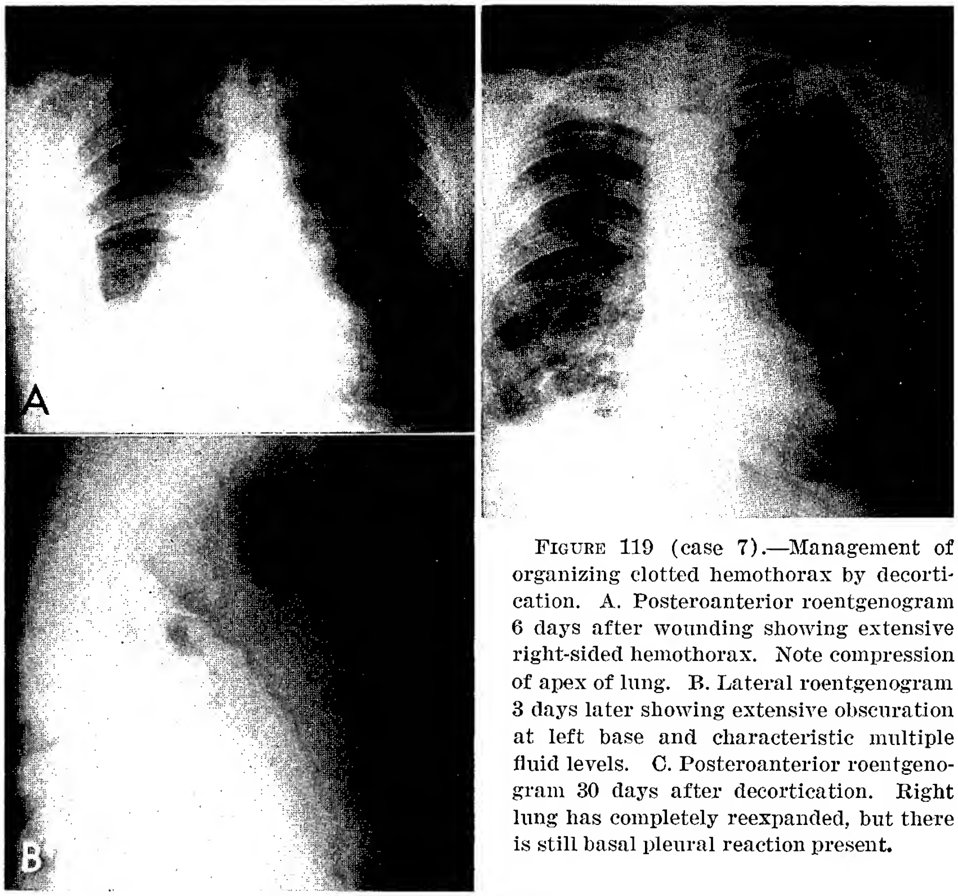

FIGURE 119 (case 7).—Management of organizing clotted hemothorax by decortication. A. Posteroanterior roentgenogram 6 days after wounding showing extensive right-sided hemothorax. Note compression of apex of lung. B. Lateral roentgenogram 3 days later showing extensive obscuration at left base and characteristic multiple fluid levels. C. Posteroanterior roentgenogram 30 days after decortication. Right lung has completely reexpanded, but there is still basal pleural reaction present.

Recovery was uneventful except for an unexplained, transient temperature elevation to 103° F. on the third postoperative day. There was no wound infection and no evidence at any time that an empyema was developing. Roentgenograms 30 days after operation (fig. 119C) showed complete pulmonary reexpansion, with a moderate residual pleural reaction at the right base. The patient was fully ambulatory when he was evacuated on 11 November.

Pleural fluid cultured at operation showed a heavy growth of nonhemolytic streptococci. Microscopic examination of the peel revealed dense fibrinopurulent exudate, beneath which was a characteristic thickened membrane of organizing fibrin, showing fibroblastic and angioblastic proliferation.

Comment.—In this case, thoracentesis was not begun until the fourth day after wounding. In spite of roentgenologic evidence of hemothorax, aspiration was increasingly less productive, and there was clear clinical evidence of infection. This is another instance of the successful performance of decortication shortly after wounding as a means of avoiding the development of empyema.

Case 8.—A 22-year-old staff sergeant sustained shell-fragment wounds of the anterior right thorax, right buttock, and right wrist on 10 November 1943. He was expectorating bright red blood when he was received in an evacuation hospital. Because of pronounced abdominal rigidity, a laparotomy was performed 12 hours after wounding. No injuries

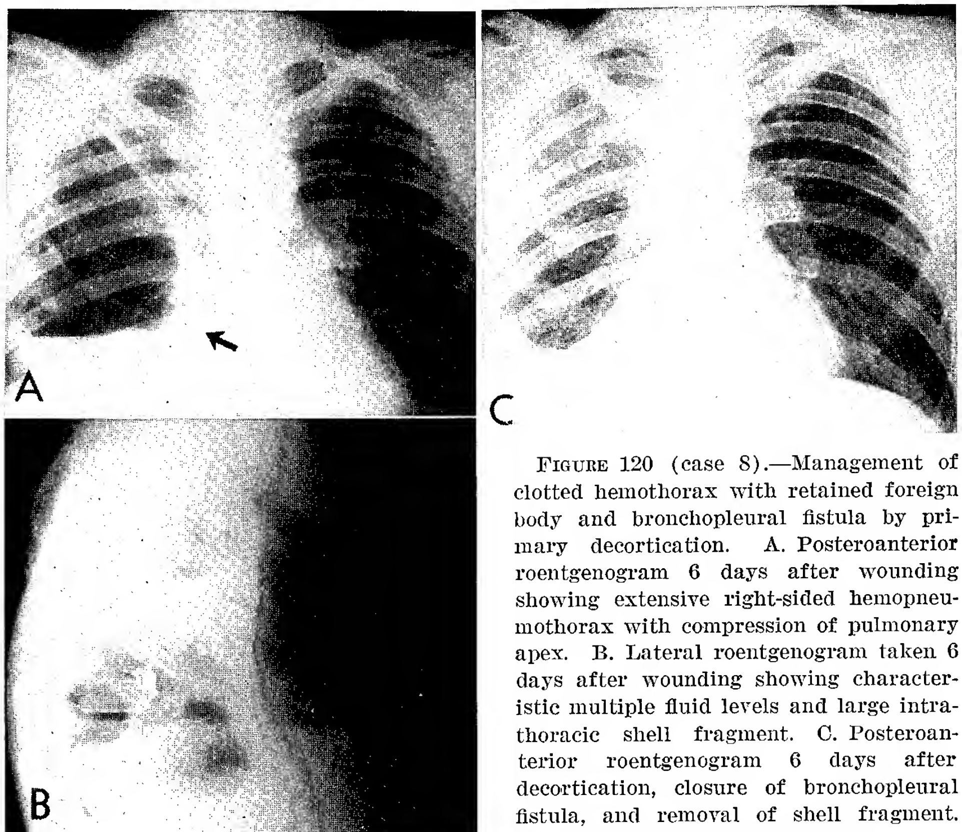

FIGURE 120 (case 8).—Management of clotted hemothorax with retained foreign body and bronchopleural fistula by primary decortication. A. Posteroanterior roentgenogram 6 days after wounding showing extensive right-sided hemopneumothorax with compression of pulmonary apex. B. Lateral roentgenogram taken 6 days after wounding showing characteristic multiple fluid levels and large intrathoracic shell fragment. C. Posteroanterior roentgenogram 6 days after decortication, closure of bronchopleural fistula, and removal of shell fragment. Lung has completely reexpanded.

were found. Thoracentesis immediately after operation yielded 500 cc. of blood, which was used for autotransfusion.

For the next 10 days, bloody fluid and air were frequently aspirated from the right hemithorax. On 16 November, an abrupt attack of dyspnea was relieved by aspiration of 1,500 cc. of air. Clinically, there was no doubt of the existence of a bronchopleural fistula. Roentgenograms (fig. 120A, B) showed a partially collapsed lung with numerous intrapleural adhesions and extensive hemopneumothorax with multiple fluid levels. A large intrapulmonary shell fragment was seen indistinctly at the inner end of the ninth rib posteriorly (fig. 120A).

When the patient was admitted to a thoracic surgery service on 30 November, he was comfortable except for moderate dyspnea. Shortly after admission, 1,250 cc. of air was removed from the pleural cavity. Final manometric negative pressures of 12, 6 cm. H_2O were maintained in spite of episodes of coughing.

Daily thoracenteses for the next 3 days yielded a total of 1,200 cc. of air and of 500 cc. of dark brownish-red fluid. The temperature rose to 102° F. daily. Two smears and a culture revealed many gram-positive intracellular and extracellular nonhemolytic streptococci.

Because of increasing toxicity and other clinical evidences of infection, thoracotomy was performed on 4 December. The pleural cavity contained 600 cc. of degenerating

blood and exudate. The lung, which was partly collapsed, was immobilized by a firm organizing peel partly covered by yellowish-green exudate. The apex of the lung was encased in a tubular sheath that was attached to the cupola of the thorax. After complete visceral decortication, the shell fragment seen in the roentgenograms was easily found and removed from the right lower lobe; it measured 20 by 7 by 5 millimeters. A posterolateral, moderate-sized bronchopleural fistula in the upper lobe was repaired with interrupted sutures of fine silk. Drainage was instituted before closure.

The lung was completely reexpanded within 48 hours. Roentgenograms on the sixth postoperative day (fig. 120C) showed no abnormality except a triangular area of density in the right cardiophrenic angle. The collection of pleural fluid which it represented was promptly absorbed.

The patient was ambulatory 7 days after operation and was asymptomatic when he was evacuated to the rear 6 weeks after wounding.

Comment.—In this case, because of increasing toxicity, decortication was performed 3½ weeks after wounding. Thoracotomy would have been indicated, in any event, for the repair of the persistent bronchopleural fistula; and the foreign body in the lung was of sufficiently large size to require removal also. The combined procedure was carried out expeditiously and without difficulty, and convalescence was uneventful. This is another instance of prompt recovery after decortication as compared with a probable long period of invalidism and disability if conservative measures had been used and if the infection of the organizing hemothorax had been allowed to progress to empyema.

Case 9.—A 24-year-old Italian officer, a prisoner of war, on 10 July 1943 sustained an extensive perforating sucking wound of the right posterior thorax, with compound comminuted fractures of the right scapula and the third, fifth, and sixth ribs. The wounds were debrided, but the pleura was not closed.

By 17 July, increasing pressure was evident in the right hemithorax, and little clinical relief was afforded by repeated aspirations. Roentgenograms (fig. 121A) showed complete collapse of the right lung, cardiac shift, and subtotal compression of the left lung. Wide

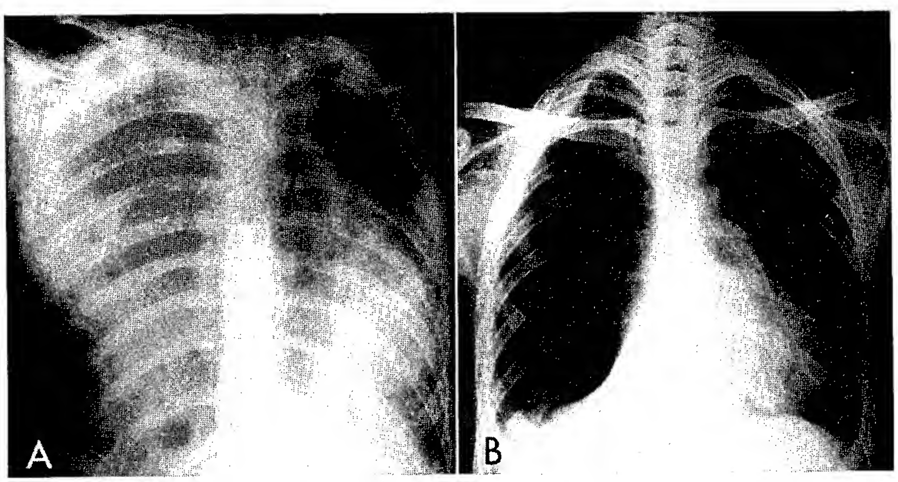

FIGURE 121 (case 9).—Management of tension hemopneumothorax and total hemothoracic empyema by secondary decortication. A. Posteroanterior roentgenogram 8 days after wounding showing enormous right-sided tension hemopneumothorax, with mediastinal herniation; cardiac shift to left; complete collapse of right lung; subtotal compression of left lung. B. Same, 23 days after institution of dependent rib-resection drainage. Right lung is still totally collapsed.

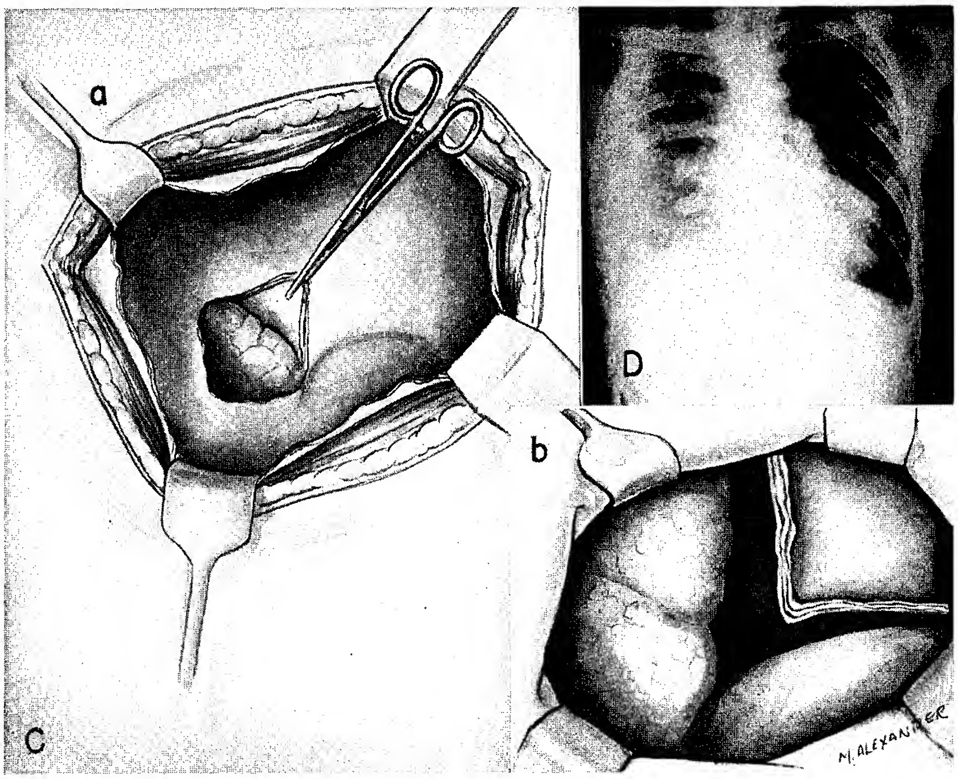

FIGURE 121.—Continued. C. Technique of right pulmonary decortication: (a) Appearance of totally collapsed right lung, which is completely immobilized by thick sheet of organizing fibrin and exudate, so that individual structures are scarcely discernible. After initial sharp dissection, a small flap of thick, organizing peel has been elevated by blunt dissection. Positive pressure has caused a slight herniation of lung through opening. (b) Mobilization of lung and diaphragm after complete decortication of visceral pleura. Visceral pleura is essentially normal and lung is expansile but not yet completely reexpanded. The ridge represents line along which thickened fibrous rind was reflected from visceral onto parietal pleurae. D. Posteroanterior roentgenogram 14 days after decortication. All drainage has ceased, and lung now completely fills pleural cavity.

mediastinal herniation and depression of the right diaphragm completed the picture of massive tension hemothorax.

The patient's condition became increasingly serious. The intrapleural tension was controlled between 20 July and 31 July by the use of an intercostal water-seal catheter, but the lung on the right continued collapsed, and a total empyema developed.

The patient was received in a thoracic surgery center on 2 August. The following day, 6 cm. of the tenth rib was resected, and a large tube was placed in the pleural cavity and connected to a water-seal bottle. For the first 24 hours, there was evidence of a small bronchopleural fistula. For the next 14 days, negative intrapleural pressure of from 10 to 15 cm. H_2O was constantly maintained. Total collapse of the right lung (fig. 121B) persisted for more than 4 weeks, in spite of the negative pressure, adequate drainage, and frequent intrapleural irrigations with aqueous solution (1:3,000) of Azochloramid (chloroazodin). Bronchoscopic examination showed no bronchial obstruction.

Sequestrectomy on the scapula was performed on 24 August. On 2 September, right-sided posterior thoracotomy was performed, with complete visceral decortication (fig. 121C). As roentgenograms had shown, the lung was found totally collapsed, and its margins could not be identified. It did not reexpand on positive pressure, and the diaphragm remained depressed and immobile. By combined blunt and sharp dissection, a proper cleavage plane was established between the visceral pleura and the adherent organized peel, which was 5 to 6 mm. thick. The visceral pleura was normally thin, but slight loss of translucency, with subpleural scarring, was observed in occasional areas. There was considerable oozing from the pleural surface.

Removal of the investing peel from the diaphragm mobilized it completely. When the lung, including the entire mediastinal surface of the upper lobe, had been completely freed, slight positive pressure produced 80-percent reexpansion. Drainage was instituted.

By the fourth day after operation, both drainage tubes had been removed, and the lung completely filled the pleural cavity. Convalescence was entirely uneventful. Two weeks after operation, roentgenograms (fig. 121D) showed the right lung to be well aerated. There was considerable resorption of the extensive peripheral reaction during the next 6 weeks. The reaction was to be expected, since no attempt had been made to remove the thick organizing peel from the parietal pleura.

When the patient was heard from by letter 3 months after operation, he had no complaints referable to the chest and was in excellent general condition.

Comment.—This is another instance of a desperately ill patient who did not respond to conservative treatment and who, as the result of decortication, was spared weeks and months of invalidism. Had conservative treatment been continued, he might have lost his life. The conditions found at operation made it clear that only decortication could have permitted the lung to expand.

Case 10.—A 26-year-old soldier, on 21 September 1943, suffered a perforating sucking wound of the left posterior thorax, with compound comminuted fractures of the seventh, eighth, and ninth ribs posteriorly. On the day of injury, the sucking wound was closed surgically by using a strip of latissimus dorsi to reinforce the intercostal muscles. The skin was left open. Five days later, although the patient seemed to be recovering satisfactorily, anterior roentgenograms showed, in addition to the rib fractures, a probable encapsulated area of pleural fluid superimposed on the cardiac shadow. They also showed a moderate amount of pulmonary infiltration that was considered due to bleeding.

On the 10th day after wounding, the patient became suddenly and rapidly dyspneic and complained of a sensation of tightness in the thorax and abdomen. When he was received in a thoracic surgery center shortly afterward, his temperature was ranging from 100° to 102° F. The left hemothorax had increased greatly, and there was some cardiac shift to the right. The immediate aspiration of 1,500 cc. of dark blood produced great subjective improvement. Smears and cultures were negative.

During the next 48 hours, although no additional blood could be aspirated from the chest, there was evidence of increasing intrapleural pressure. Roentgenograms (fig. 122A) showed increased left-sided obscuration, with further cardiac and mediastinal shift.

Left posterior thoracotomy was performed on 5 October, 14 days after injury. Fragmented portions of the three fractured ribs were removed, and the pleural cavity was entered through the eighth intercostal interspace. The lung was 75 percent collapsed. The pleural space was filled with about 1,000 cc. of firmly clotted blood; there was practically no liquid blood. A thin layer of fibrin, which showed early organization, was removed from the visceral pleural surface.

Posterolaterally, there was a laceration in the left upper lobe, 3 cm. deep, which contained four fragments of ribs. The lung bled briskly when these were removed. The laceration was repaired with fine silk. Anterior and posterolateral intercostal water-seal drainage was instituted. Closure of the chest wall was difficult posteriorly in the area in which the wound of entrance had been excised.

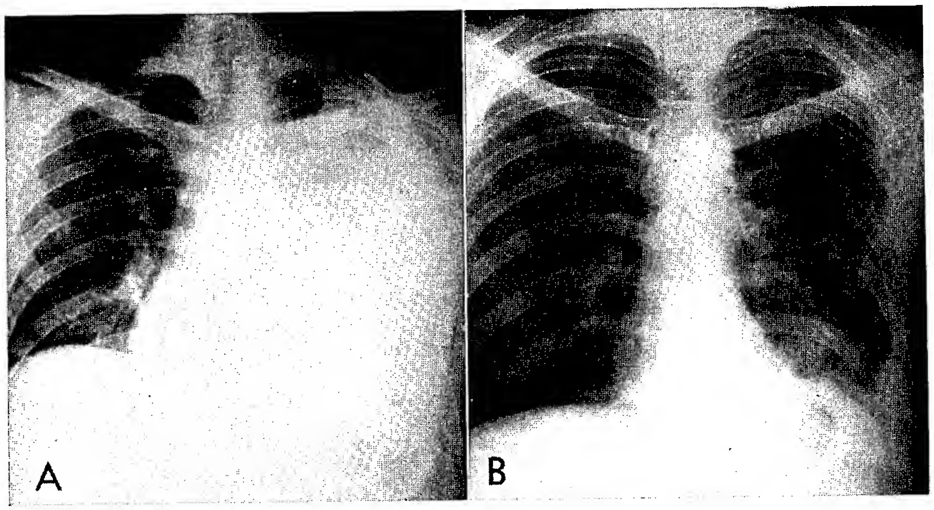

FIGURE 122 (case 10).—Management of infected clotted hemothorax by early primary decortication. A. Posteroanterior roentgenogram 17 days after wounding and 7 days after thoracentesis, showing large hemorrhage on left, with cardiac shift to right. B. Same, 6 weeks after decortication and 2 weeks after secondary rib-resection drainage of small postoperative empyema. Pulmonary field is now clear, and posterolateral empyema has been well drained.

Both grossly and microscopically, the organizing exudate showed miliary abscesses. Culture of the blood clot removed at operation was positive for aerobic hemolytic *Staphylococcus aureus*.

Within 48 hours, thin, purulent drainage was evident from the lower tube. At this time, roentgenograms showed the lung to be well expanded at the apex. Laterally, an oval area of obscuration was seen, which later proved to be a small loculated empyema. By the seventh day after operation, the posterior portion of the incision, in the area in which the entrance wound had been excised, had become grossly infected. By the 14th day, it was evident that the localized empyema just described was connected with a small bronchopleural fistula and that intercostal drainage was not adequate. The following day, a 15-cm. segment of the ninth rib was removed, and the empyema cavity was opened widely and packed.

Convalescence thereafter was rapid. The small bronchopleural fistula closed spontaneously. When the patient was evacuated to the Zone of Interior 6 weeks after the second operation, roentgenograms (fig. 122B) showed good pulmonary expansion and almost complete clearing of the lateral and basal obscuration.

Comment.—This case is an illustration of the difficulties and complications which could arise when thoracentesis was delayed. It was not resorted to in this case until the 10th day after wounding, when the patient was seriously ill, and when, as later ineffectual aspirations showed, organization of the clot had already begun. The seriousness of his condition, with evidence of beginning infection, was considered a justification for early decortication, only 14 days after wounding. Miliary abscesses were already present at operation, and empyema developed later, but the cavity was small and the response to standard measures was good. This is another patient who would undoubtedly have gone on to a long period of established infection if decortication had not been resorted to promptly.

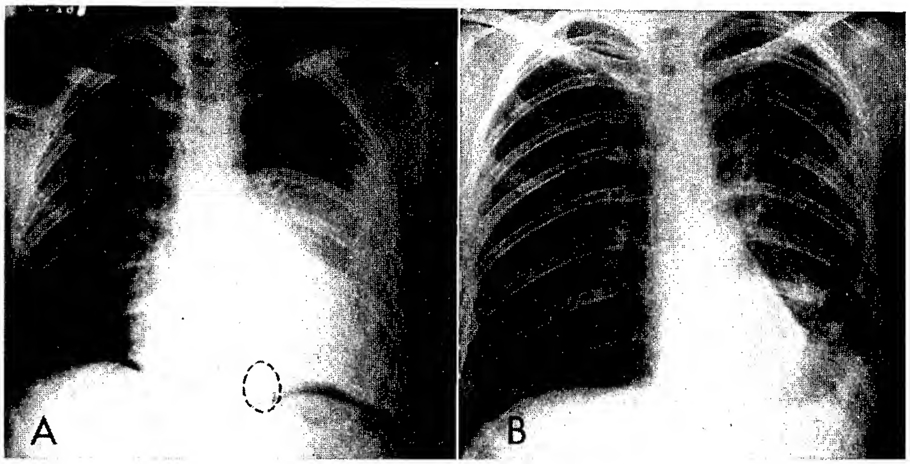

FIGURE 123 (case 11).—Management of infected clotted hemothorax, complicated by segmental pulmonary necrosis and retained foreign body, by early primary decortication. A. Posteroanterior roentgenogram, 10 days after wounding and after induction of diagnostic pneumoperitoneum for localization of foreign body. Note large left-sided hemothorax, which has increased in size in spite of repeated thoracenteses. B. Same, 8 weeks after wounding and 6½ weeks after primary decortication, segmental lobectomy, and removal of shell fragment.

Case 11.—A 19-year-old soldier sustained a penetrating wound of the left thorax on the Salerno beachhead on 11 September 1943. There was no hemoptysis or dyspnea at any time. Roentgenologic examination on 16 September showed a hemothorax of moderate size and a large shell fragment lying well posteriorly at the level of the tenth interspace.

At this time the patient was somewhat toxic. His fever increased progressively, the highest elevation being 103.4° F. Repeated aspirations were productive of only small amounts of old, sterile blood. After diagnostic pneumoperitoneum on 20 September, roentgenograms (fig. 123A) showed that fluid was increasing in the left thorax, in spite of repeated thoracenteses.

On 23 September, left posterior thoracotomy was performed through the sixth intercostal space, after removal of posterior segments of the sixth and seventh ribs. The lung was collapsed, and there was extensive clotting of the hemothorax, with early organization. The shell fragment, which was intrapleural and had no clothing attached to it, measured 22 by 16 by 11 millimeters. It lay in a loculus of clotted blood mixed with greenish exudate, which had a foul odor. After the pleural cavity had been emptied, decortication showed the visceral pleura to be relatively normal. The lower half of the lower left pulmonary lobe was so badly lacerated and necrotic that segmental lobectomy was necessary. Drainage was instituted. Bronchoscopy at the end of the procedure produced bloodstained mucus.

Cultures of the organizing blood clot showed a mixture of staphylococci and anaerobic nonhemolytic streptococci.

After operation, the lung reexpanded well at the apex, but a loculated pocket of serosanguineous fluid developed in the axilla. It cleared with aspiration.

For the first 14 days after operation, the temperature ranged from 101° to 103° F. By the end of this time, drainage from the posterior intercostal tube had become purulent. When the tube was removed on 10 October, after drainage had apparently ceased, there was an immediate febrile flareup, and roentgenograms showed increased basal obscuration.

On 16 October, open thoracotomy, with rib resection, was performed and tube drainage was instituted. The small basal empyema was rapidly obliterated, and roentgenograms taken on 13 November (fig. 123B) showed complete left-sided pulmonary expansion, with a minimal pleural reaction at the base. The patient was in excellent condition when he was evacuated to the Zone of Interior a few days later.

Comment.—In this case, decortication was performed in the face of existing infection and pulmonary necrosis. Convalescence was stormy, but the postoperative empyema was basal and readily cleared with the proper drainage. This case represents one of the few in the Mediterranean theater in which segmental lobectomy or any other excisional pulmonary operation was necessary.[6]

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[6] The reader is referred to chapter XI (p. 441) for long-term followup studies on casualties whose chest wounds were complicated by hemothorax and hemothoracic empyema.

CHAPTER VII

Management of Retained Intrathoracic Foreign Bodies, Mediterranean (Formerly North African) Theater of Operations

Lyman A. Brewer III, M.D., and Thomas H. Burford, M.D.

INCIDENCE

Experience in the Mediterranean Theater of Operations, U.S. Army, during World War II showed that, exclusive of those in the heart and pericardium, which are discussed separately (p. 49), retained intrathoracic foreign bodies could be anticipated in approximately one out of every four penetrating chest wounds.

The remarkable paucity of recorded cases of retained foreign bodies after World War I leads to two possible assumptions, (1) that the majority of patients from whom missiles were not removed remained symptom-free, or (2) that they were unaware of their condition. In view of the general apprehension known to be felt when casualties were aware that they were harboring foreign bodies, the second assumption seems likely as the explanation of a considerable number of cases.

INDICATIONS FOR SURGERY

Experience with retained intrathoracic foreign bodies in civilian practice was not of great help to military surgeons because in civilian practice, the patient could be observed and the object removed electively if it became symptomatic. In military practice, the surgeon had to decide with reasonable promptness whether the patient could be safely returned to duty with the foreign body in situ, which meant that he had to predict the chances of the development of future complications, including infection.

Wounding agents.—Generally speaking, if the foreign body was a bullet, it was less likely to cause complications than if it were a shell fragment or rib fragments.

Bone fragments from fractured ribs furnished a special problem. Such fragments, set in motion by the impact of the missile, were far more apt to produce lung damage, because of their irregular, jagged surfaces, than metallic foreign bodies. They were more frequently found in the lung than were metal-

lic objects. They were not usually seen on preoperative roentgenograms, and unless they presented themselves on inspection or palpation, they were often not recognized at operation. A prolonged search for them, such as might be undertaken for known metallic objects, was therefore seldom carried out. If, however, they were seen in the lung through the pleural defect after debridement had been completed, particularly if there were extensive lacerations of the pulmonary parenchyma, it was best to remove the fragments and repair the damage without delay.

This was particularly true when the bone fragments were partly in the parenchyma and partly in the pleural space, a location in which they were likely to produce considerable trauma as the lung reexpanded and came into contact with the chest wall. The result was an air leak in some cases, and provision of an avenue of infection in others. Fortunately, bone spicules partly in the lung and partly in the parenchyma were usually found and removed without difficulty.

Accessibility of objects.—If it was necessary to explore the pleura in the course of initial wound surgery in thoracic wounds, the obvious course was to remove any accessible foreign objects, regardless of size. This course, however, was not justified if only debridement was required, nor was it employed in the emergency treatment of sucking wounds.

The majority of foreign bodies were located in the periphery of the lung, where their removal was often—though not always—simple because they were accessible (vol. I). The mere presence of an object in the parenchyma, however, was not in itself an indication for its removal.

Size of objects.—The size of the object also played a part in the decision for or against removal. Early in the war, and especially with the establishment of the first thoracic surgery center in the North African theater, the policy was adopted of removing all shell fragments 0.8 cm. in diameter or larger seen on posteroanterior roentgenograms. At this time, it was thought that removal would be simple because the location, by palpation, of objects of this size would furnish no difficulty. Later, when the experience was evaluated, it was found that it furnished a great deal, and the policy was therefore changed, so that only foreign bodies of 1.5 cm. in diameter or larger were removed routinely. This policy, which avoided a great deal of pulmonary trauma, proved increasingly satisfactory, and added experience furnished no reason to alter this limit in the absence of other indications for surgery.

There was never any question that very large objects (over 1.5 cm. in length) should be removed, either in the forward or the base area—that is, during other procedures or electively—as soon as possible. Here, the question was one of timing, not of indication. If the objects were small, not more than 1 or 2 cm. in length, they could be let alone unless they were near the heart, a large vessel, or the esophagus; then they were removed. If foreign bodies near vital structures were let alone until complications had developed, their removal was hazardous.

Infection.—It was recognized that the lung and pleura tolerate foreign bodies well and that many of these retained objects were sterile. Many of them, however, were not, for fragments of ribs, bits of clothing, and other debris were often carried into the chest with the missile and furnished a nidus for infection. Infection was particularly likely when the object was irregular. On the other hand, foreign material was not necessarily a source of infection. In one series studied in the Mediterranean theater, a little over half of the foreign objects removed had bits of clothing about them, but in no instance, aside from 4 cases in which lung abscesses had already developed, could positive cultures be obtained from the missile cavity. Unfortunately, it was not possible to predict, without surgical investigation, in which cases foreign material other than the missiles was present and, if it were, in which cases infection would develop.

Pulmonary infection associated with a retained foreign body was also an indication for surgical intervention. Exploration of the chest and removal of the foreign body before infection developed practically always was followed by a speedy recovery, whereas the delayed treatment of a pulmonary abscess about a foreign body was attended with grave risks.

It was necessary to consider the possible presence of a foreign body in any instance of prolonged pulmonary suppuration after wounding. In an occasional case, a drainage tube which had not been securely anchored and had slipped into the chest might be the cause of the trouble. This possibility made it particularly important that the record state clearly the presence and location of all such tubes.[1] [2]

Clinical considerations.—Hemoptysis associated with a retained foreign body was a positive indication for its removal (fig. 71).

Pain was a difficult symptom to evaluate. In most instances, it was connected with the wound in the chest wall and had no connection at all with the presence of the object, though it was not always possible to convince soldiers of this fact.

Psychic manifestations, in fact, played an extremely important part in the decision for or against removal. Many men were seriously disturbed by the knowledge that they had one or more shell fragments in the chest. It was repeatedly observed that a patient who harbored a large foreign body in the thigh, for instance, and a very much smaller one in the pulmonary parenchyma, ignored the former and became lung-conscious because of the presence of the latter. Reassurance by the surgeon that the pulmonary object was unlikely to

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[1] Loss of drainage tubes into the pleural cavity seems to be an important cause of chronic empyema. The exact number of such cases encountered in Veterans' Administration hospitals is not clear, but one of the authors of this chapter has performed several operations for this cause. The experience suggests to him that it is important that the presence of a drainage tube be specifically recorded each time a dressing is changed; failure to find it on subsequent dressings would then be an indication for roentgenologic study and an attempt to retrieve it, which is not a difficult matter if it is searched for immediately. Within 48 hours or longer, the pleura may seal over it and surgery may be required for its removal.—L. A. B. III.

[2] The obvious solution of this problem is, of course, prophylactic—the attachment of a safety pin or other radiopaque marker to every drainage tube.—F. B. B.

give him trouble sometimes satisfied him, but in borderline cases, of course, no honest guarantee could be given that he would be immune from late complications. In such cases, the policy was to remove the object.

It was also the policy to remove the object when the patient with an intrathoracic foreign body complained of vague pains in the chest, shortness of breath, and other subjective symptoms. If these manifestations persisted, his emotional attitude, quite aside from any physical considerations, would obviously interfere with his return to duty, and the proper course was to remove the retained missile.

Conclusions.—The final decision concerning removal was based on a number of factors, including the size and shape of the foreign body; whether there were multiple or single objects; the location of the object or objects; the presence or absence of symptoms which could be attributed to the presence of the object; and the patient's ability to withstand surgery. Objects which had been retained from 10 to 14 days were unlikely to cause immediate trouble, and individualization of each case was therefore possible. As a matter of fact, a theater policy regarding the removal of foreign bodies was necessarily tentative; whether retained objects would give future trouble was a question which could be answered only by followup in the future.

SURGICAL TIMING

Although there was eventually a fair amount of agreement concerning the size of foreign bodies for which removal was indicated, the proper time for operation remained the subject of considerable discussion until the end of the war.

The removal of foreign bodies could seldom be justified as an indication for thoracotomy in forward areas, especially when immediate evacuation to the rear was contemplated. Removal of the objects within 24 to 48 hours, unless they were encountered in the course of initial wound surgery, was generally frowned upon. The surgical risk, the rate of infection, and the morbidity from other causes were all increased when this practice was followed. Experience proved that only a very few objects gave rise to any difficulty if they were left in situ until the patient was evacuated to a fixed hospital (vol. I). It was therefore the policy to leave them undisturbed when thoracotomy was done on some valid indication in a field or evacuation hospital unless they were readily accessible. When the missile could be seen under the fluoroscope to be pointing against a large vessel and moving with each pulsation, prompt removal was obviously indicated.

Very few experienced thoracic surgeons removed retained foreign bodies until at least 14 days after wounding. By this time, pulmonary equilibrium had been reestablished. Traumatic wet lung had been controlled, with reaeration of alveoli, absorption of interstitial fluid, removal of extravasated intrapulmonary blood, and reestablishment of normal tracheobronchial patency.

Technically, it was far easier to locate metallic fragments in crepitant, aerated pulmonary tissue than in the boggy, indurated tissue present soon after injury. The lung was better able to withstand lobotomy after it had recovered to some extent from the original injury. Finally, secondary closure of debrided wounds had usually been accomplished within the period specified, and the absence of granulating wounds in the chest wall greatly reduced the hazard of infection. The general policy was to close open wounds in the chest wall by delayed primary wound closure at least 24 hours before thoracotomy for removal of retained foreign bodies. The incision for the thoracotomy was then so planned that these wounds were avoided. It was even better if the operation could be deferred until the chest wound was solidly healed, especially if it had to be traversed in performance of the thoracotomy for removal of the foreign body.

The status of the wound in the chest wall played a part in the end results of removal of foreign bodies. In 102 operations in one series (p. 349), 3 of the 4 empyemas which developed after operation were directly attributable to the presence of an unhealed wound in the thoracic wall at the time of operation.

By the policy of delayed surgery, the patient was in a hospital toward the rear, where more detailed study could be made and the decision for or against removal of the foreign body arrived at deliberately, and not under the stress of combat conditions in a forward hospital. Better preoperative and postoperative care was also available in a fixed hospital, in which the patient could be kept as long as was necessary. All the circumstances, therefore, were more favorable for success than they were after a hasty operation performed as an emergency before cardiorespiratory equilibrium was reestablished.

While foreign bodies were frequently removed without difficulty weeks and even months after wounding, long delays were not desirable if it was clear that the objects must be removed. When more than 2 weeks had elapsed, the increased fibrosis present around them sometimes made repair and closure of the parenchymal incision more difficult. Extensive intrapleural adhesions, composed of fibrous tissue, sometimes made it difficult to palpate the object within the lung, and separation of the adhesions was likely to be time consuming and associated with considerable oozing. In addition, the fibrous tissue reaction which had usually developed around the object by this time itself resulted in the creation of a space in the lung that was often difficult to obliterate.

Delay in the removal of the foreign body when its excision was clearly indicated was sometimes necessary because of other wounds. One patient, for instance, with a spinal injury, also harbored a large intrapleural foreign body 6 by 3 by 2 centimeters. The size of the object furnished a clear indication for its removal, but the condition of the patient because of his spinal injury made it impossible to operate on him until 20 days after wounding. By this time, the missile had produced so much erosion of lung tissue that a bronchopleural fistula had formed; empyema had then developed; and a severe intrapleural hemorrhage occurred and was a contributing cause of death. In retrospect, an

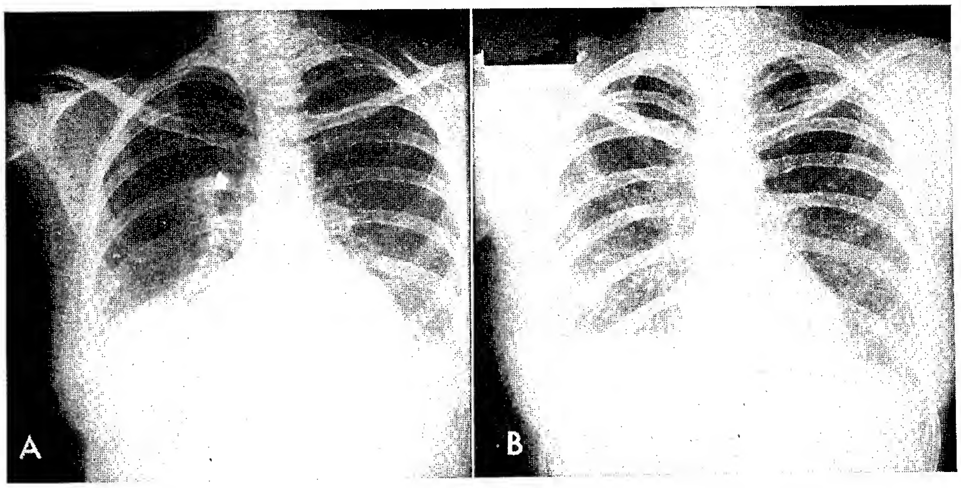

FIGURE 124 (case 1).—Retained foreign body in lung. A. Posteroanterior roentgenogram showing metallic foreign body in upper lobe of right lung immediately after wounding. B. Same, 2 weeks after thoracotomy and removal of foreign body.

earlier attempt to remove the foreign body, in spite of the surgical risk presented by the patient, might have been lifesaving.

The following case reports are not exceptional. They are typical of the favorable results consistently obtained when retained intrathoracic foreign bodies were correctly handled, according to the principles of management standardized in the Mediterranean theater.

Case 1.—A U.S. Army nurse, when struck by a bomb fragment on 29 March 1944, sustained a penetrating, sucking wound of the right chest and a right-sided hemopneumothorax. The bomb fragment lodged in the right upper lobe.

The wound of entry was debrided and the sucking wound closed, after which thoracentesis was instituted. Closure was completed by delayed primary wound closure 5 days later.

Fluoroscopic and roentgenologic localization revealed a fragment 1.5 cm. in its greatest diameter lying in the upper lobe of the right lung (fig. 124A). Thoracotomy, without costal section or resection, was done 4 weeks after injury, and the fragment was removed.

The patient made an uneventful recovery (fig. 124B). Her transfer to the Zone of Interior for reassignment was for psychic rather than physical factors.

Case 2.—This patient, who was wounded by a high-velocity missile, underwent thorough debridement at an evacuation hospital, after adequate resuscitation, and was evacuated to a thoracic center 4 days after injury. The wound was closed on the fifth day and healing per primam occurred. Aspiration of a hemothorax of moderate size, which had been begun in the evacuation hospital, was continued daily until the pleural space was empty.

Accurate localization of the missile to the posterior portion of the apex of the left lower lobe was accomplished by roentgenologic examination in two planes (fig. 125A and B). Thoracotomy, without costal section or resection, was performed on the 12th day after wounding. The object was removed without difficulty.

Convalescence was entirely uneventful. One week after thoracotomy, the lung was clear and well expanded (fig. 125C), and the pleural space contained neither air nor fluid. Ten days after operation, the wound was solidly healed; the patient was progressively

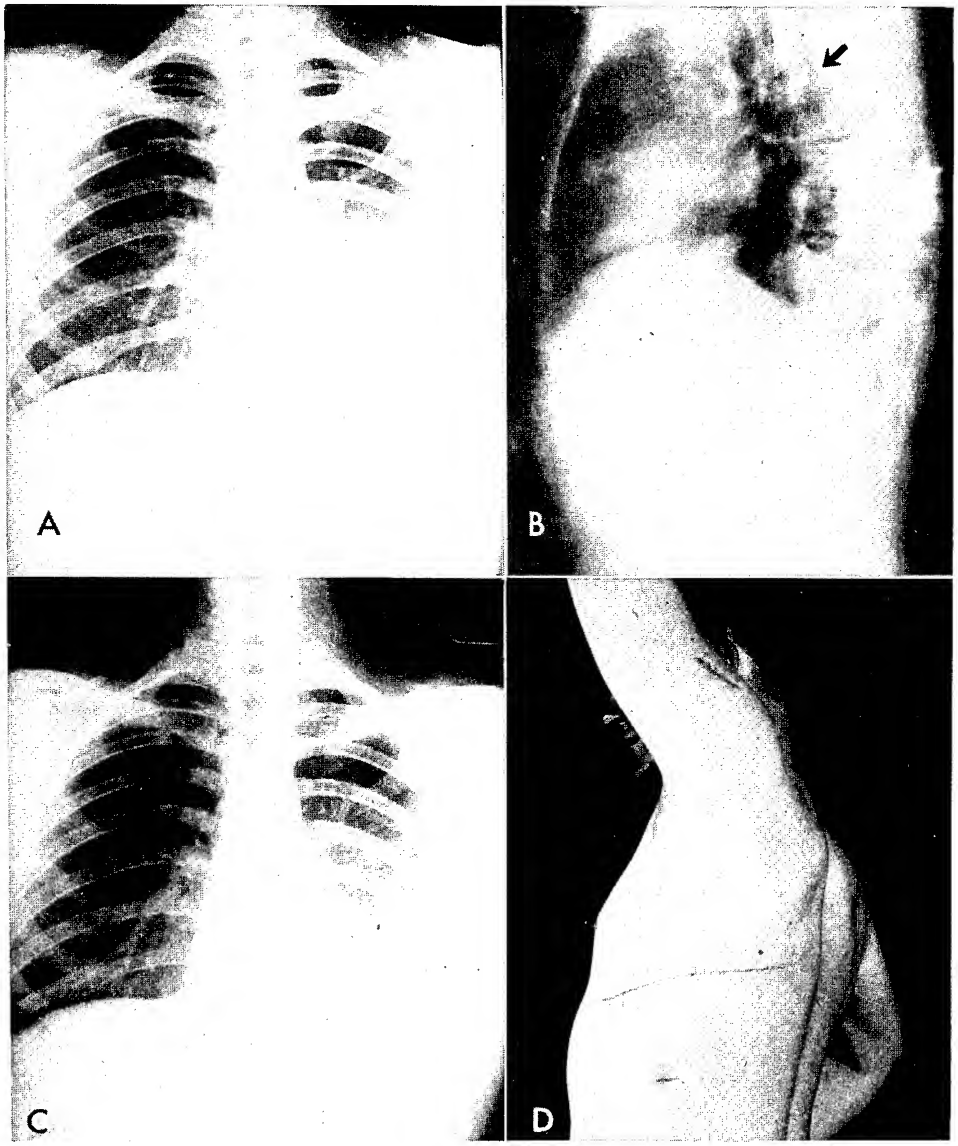

FIGURE 125 (case 2).—Retained foreign body in lung. A. Posteroanterior roentgenogram showing missile in left lung field. The obscuration is the result of an organizing peel on the pleural surfaces. B. Lateral roentgenogram. C. Posteroanterior roentgenogram 7 days after thoracotomy and removal of foreign body. Lung is now completely expanded. D. Photograph of patient 10 days after operation. Note well-healed scar and full range of arm motion at this time.

ambulant; and he had a full range of arm and shoulder motion (fig. 125D). Within 22 days after injury, the reparative phase of management was completed and, after a brief period of rehabilitation, return to full duty was anticipated.

TECHNIQUES OF LOCALIZATION

Thoracotomy for the removal of foreign bodies retained in the pleural cavity and the lungs was a safe and rational procedure only when the preoperative localization of these objects had been sufficiently accurate for their removal without extensive manipulations and an extended search for them. Only by the possession of reliable information concerning their location could there be a logical surgical approach.

General considerations.—While all phases of localization were important, the first problem that concerned the thoracic surgeon was whether the foreign body lay within the confines of the pleura or in the extrapleural tissues. Many objects in the chest wall could be removed under local analgesia, and no specialized training was required for their proper management. The object which lay within the pleural cavity necessitated a very different intellectual and technical approach from that which would be used for an entirely extrapleural foreign body in the chest wall. Once the pleural boundary had been crossed, the surgeon was confronted with a host of problems, such as the management of open pneumothorax and the necessity for positive pressure anesthesia, which required specialized training for their solution.

In a war zone, there was frequently not at hand the equipment commonly employed in peacetime for the accurate localization of intrathoracic foreign bodies, such as stereoscopy, the parallax method, and electric locators. That did not mean, however, that accurate localization could not be accomplished in almost every case if cognizance was taken of basic principles and if a systematized plan of study was followed. The plan to be described proved its efficiency in the localization of several hundred foreign bodies in the chest observed in the Mediterranean theater.

Physical examination.—Careful palpation, if successful, was the most accurate possible method of determining the location of a foreign body. Palpation soon after wounding might be futile because of tenderness and spasm. When they had disappeared, palpation was frequently very useful.

Case 3.—This patient received a chest wound from an enemy machine pistol, the bullet coming to lie in the soft tissues of the posterior thoracic cage. It was easily visualized (fig. 126) by posteroanterior and lateral films. When the patient was admitted to the chest center, the bullet could not be palpated. As spasm and tenderness subsided, it was readily palpable. At operation, it was found lying in the erector spinae muscles and was recovered without difficulty under local anesthesia.

Roentgenologic examination.—The study of a patient with a foreign body in the chest began with routine posteroanterior and lateral roentgenograms. Although in numerous instances, these two views apparently sufficed

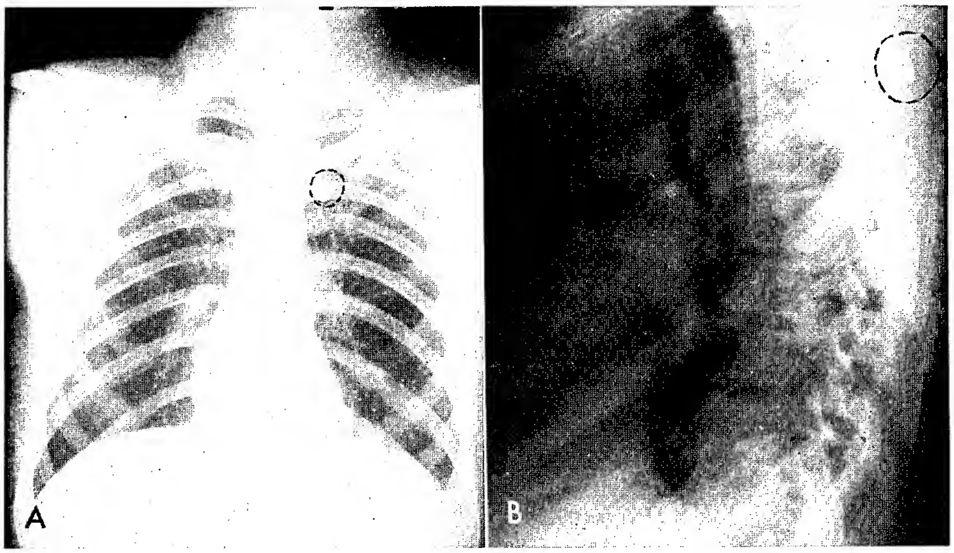

FIGURE 126 (case 3).—Retained foreign body in posterior chest wall. A. Posteroanterior roentgenogram showing missile probably in thoracic wall. B. Lateral roentgenogram. At operation, the missile was found in the erector spinae muscles.

for accurate localization, in general, they were usually considered as little more than scout films, to indicate the direction that subsequent investigation should take. To rely solely upon them could easily lead to grief. That one view was worthless for localizing purposes seems almost too obvious to mention, but occasionally, a patient was encountered whose chest had been explored—fruitlessly—on the basis of a single film.

In the examination of the initial films, the chest was divided into sectors (fig. 127), which made it possible to determine certain facts at once. If the object lay outside of these sectors, it was clear that it was extrapleural. To illustrate:

Let it be assumed that a missile lies on the right side of the chest, in sector B–B′ (fig. 127). If only the posteroanterior film were examined, the object could lie anywhere in the sagittal plane of the right mid hemithorax. Further examination of the lateral film clarified the matter. If the object lay in the anterior chest wall, it would appear in sector A′. If it were in the tissues of the posterior chest wall, it would lie in sector C′. Since, in the lateral view, it lay in sector B′, it was assumed to lie in the midcoronal plane, and to be intrapulmonary, as it proved to be:

Case 4.—This patient was struck in the right side of the chest by a German rifle bullet. Examination of posteroanterior and lateral films (fig. 127) showed that it lay in sector B–B′. At operation, the missile, which was the brass jacket of a rifle bullet, was removed from the right middle lobe.

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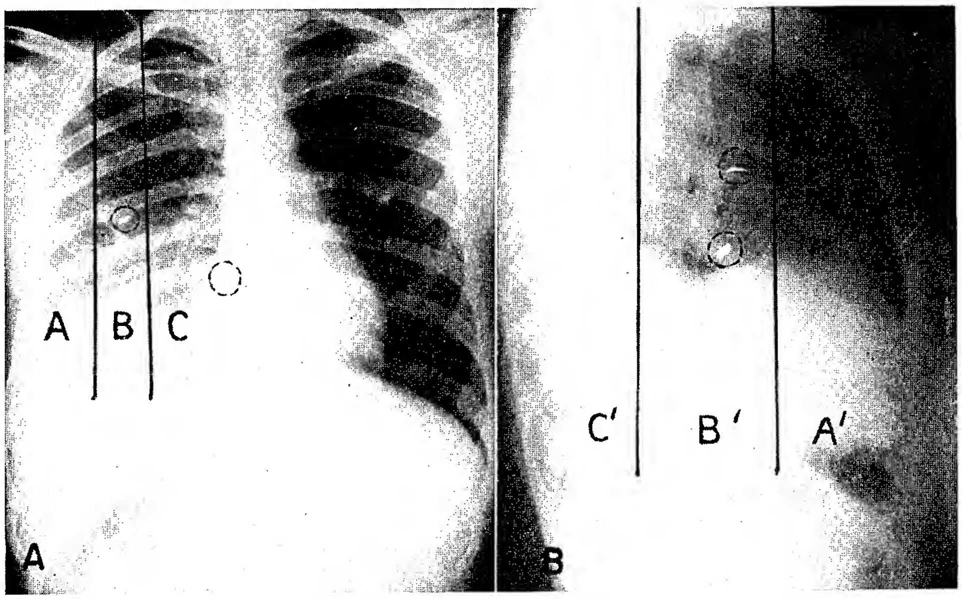

Figure 127 (case 4).—Localization of intrathoracic foreign bodies by division of chest into arbitrary sectors. A. Posteroanterior roentgenogram showing object in lung. B. Lateral roentgenogram.

Both suspected and unsuspected foreign bodies frequently came to light after withdrawal of fluid or air or both from the chest, with resulting reexpansion of the lung and coincidental changes in position of the object (fig. 128). Such evidence was always looked for on serial films. Foreign bodies observed in serial films to have dropped from apex to base were intrapleural and extrapulmonary. A characteristic positional change related to movement of the shoulder girdle or of large muscle group of the chest wall furnished prima facie evidence that the foreign body was extrapleural.

The following case history illustrates this situation:

Case 5.—In this case, the foreign body was found in sector B in the left side of the chest (fig. 129A). It seemed suspended high in the center of a pneumothorax pocket, with no visible means of support. Since it did not drop to the bottom of the pleural cavity, it could not possibly lie free within it. When the lung was completely reexpanded (fig. 129B), there was no significant positional change; the slight change in the axis of the metallic fragment was caused by elevation of the shoulders. This phenomenon was frequently helpful in localizing foreign bodies in and about the scapula and clavicle.

At operation, this shell fragment was removed from a location deep to the pectoralis major muscle, just inferior to the left clavicle.

The closer the foreign body lay to the pleural surface, the more difficult it was to be certain that it lay within the lung tissue. In fact, if it lay in sectors other than B–B′, posterolateral and anterior films were inadequate, and recourse to supplemental procedures was necessary.

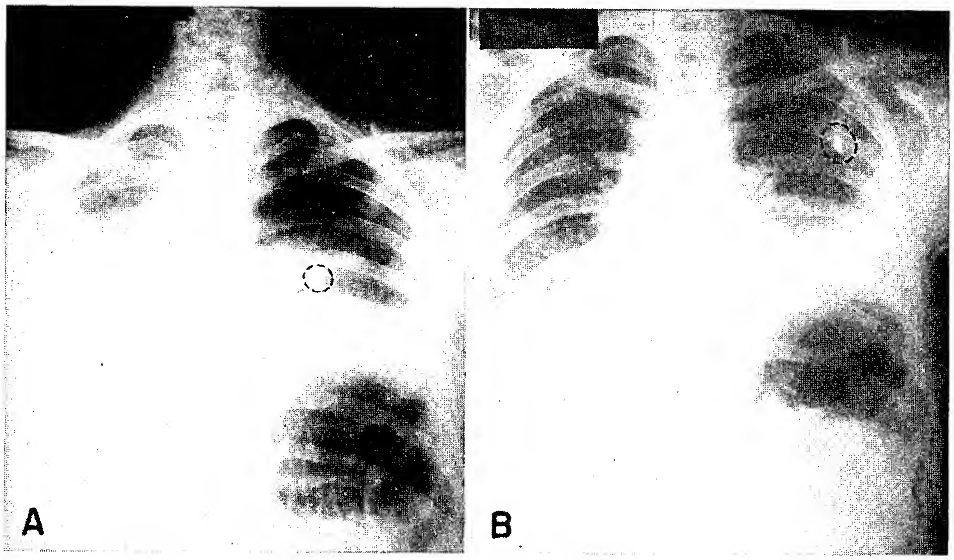

FIGURE 128.—Localization of intrathoracic foreign body. A. Posteroanterior roentgenogram showing foreign body in undetermined location. B. Same, after expansion of lung. The change of position of the object with the movement of the lung shows that it is intrapulmonary.

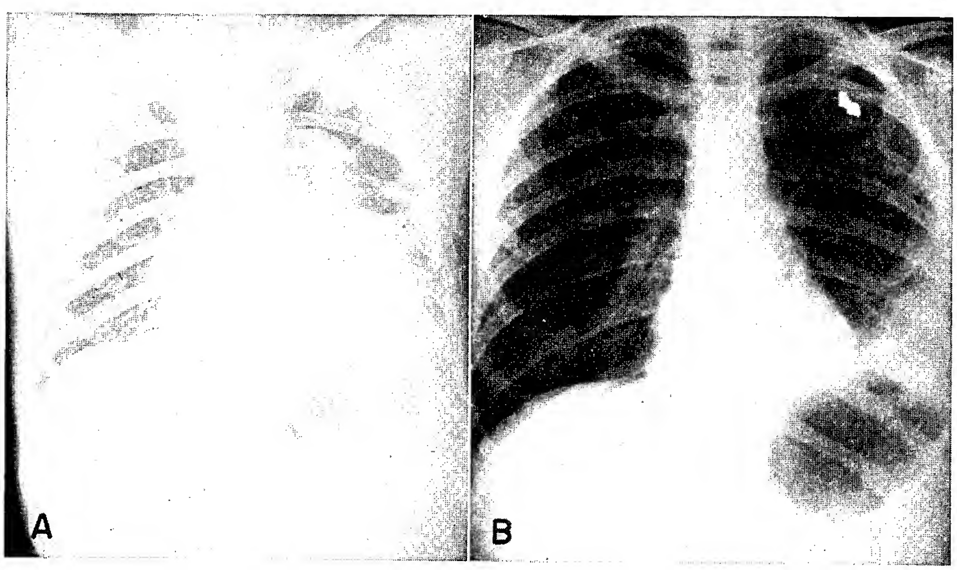

FIGURE 129 (case 5).—Localization of foreign body in chest wall. A. Posteroanterior roentgenogram. B. Reexpansion of lung. Missile has not moved. The change in its axis is explained by the difference in the position of the shoulder girdle in the two views. At operation, it was removed from the chest wall just inferior to the left clavicle.

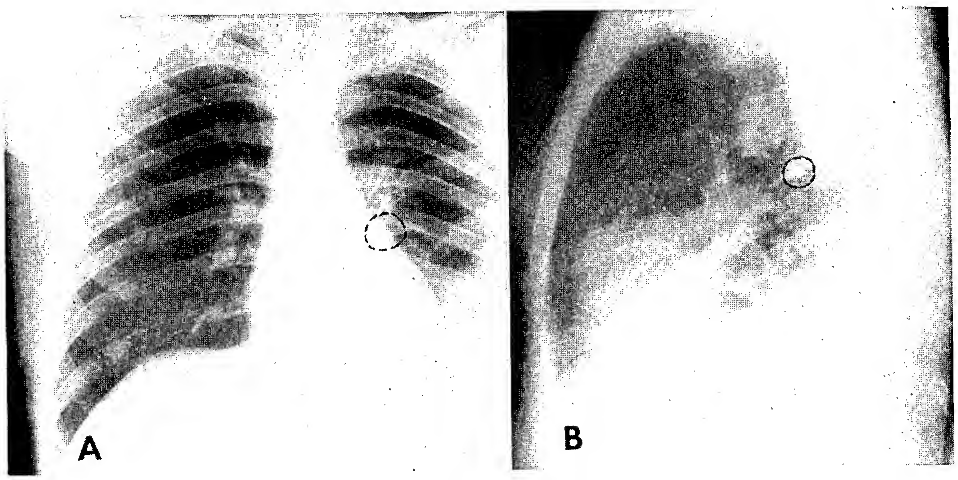

FIGURE 130 (case 6).—Localization of intrapulmonary foreign body. A. Posteroanterior roentgenogram. B. Lateral roentgenogram. At operation, the missile was removed from the left lower lobe.

Fluoroscopy.—If, during the examination under the fluoroscope, the retained missile was observed to move the distance of an interspace with the respiratory act, it was assumed to be intrapulmonary. If it moved synchronously with the cardiac pulsations, then it might be in the lung or in the mediastinum.

Case 6.—This patient, an Italian prisoner of war, was struck in the left chest by a high explosive fragment. On fluoroscopic examination, the object was seen to move synchronously with the respiratory excursions. Posteroanterior and lateral films (fig. 130) showed it lying in sector C–C′.

At thoracotomy, it was removed without difficulty from deep in the left lower lobe.

Case 7.—This patient was struck in the left chest by a high explosive fragment. Examination of the posteroanterior and lateral films placed the object in sector A–C′ (fig. 131). It was not possible to determine, from the films alone, that the fragment did not lie outside the bony cage. Fluoroscopy projected the missile within the arc of the ribs and thus in lung tissue.

At thoracotomy, the missile was removed from the left lower lobe.

Fluoroscopic examination was supplemented by spot films made by a special technique whenever the missile was in a peripheral sector and had not been located by other means. Under fluoroscopic visualization, the patient was rotated so that the foreign body was brought to the position apparently nearest to the external thoracic surface. In this profile position, as the following case shows, it was usually possible to determine whether the object was extrapleural, intrapleural, or intrapulmonary. Spot films were made for more deliberate study:

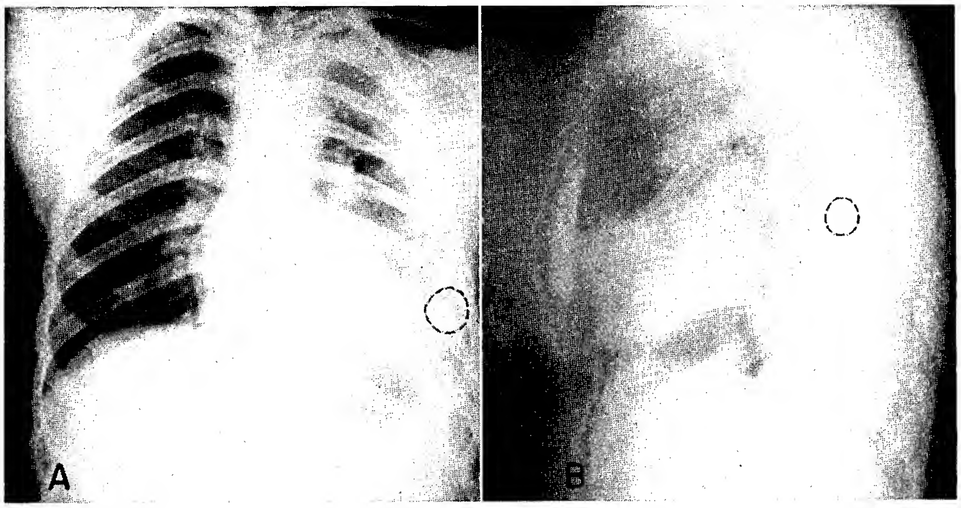

FIGURE 131 (case 7).—Localization of foreign body in lung. A. Posteroanterior roentgenogram showing missile on left in indeterminate position. B. Lateral roentgenogram, which is equally inconclusive. Fluoroscopy was necessary in this case to localize the object in the left lower lobe.

Case 8.—This patient was wounded by a high explosive fragment. The foreign body lay in sector A–B′ (figs. 132A and B). When objects were in this location, it was impossible, without supplemental studies, to be certain that they lay intrapleurally or extrapleurally. Utilizing fluoroscopy, with rotation of the patient, an additional roentgenogram (fig. 132C) showed that the object lay outside the lung surface. Since, furthermore, it was projected external to the inner margin of the rib, it necessarily lay in the thoracic wall and not within the pleural cavity. The straight line of increased density shown in the roentgenogram in this position was due, as in similar cases, to an extrapleural hematoma associated with the metallic object deep in the thoracic wall.

Diagnostic pneumothorax.—If the issue was still in doubt, the matter could usually be promptly settled by diagnostic pneumothorax (fig. 133). When air was injected into the chest and the foreign body underwent positional changes coincidental with those observed in the lung, it was obviously intrapulmonary. If it remained in its original position, as in the following case, it was obviously extrapulmonary.

Case 9.—This patient sustained multiple penetrating chest wounds from high explosive fragments. Two objects lay in the soft tissues of the lower lateral chest wall (fig. 134). The third object lay in sector B–C′, in which supplemental studies are practically always required. Diagnostic pneumothorax did not alter the position of the fragment.

The extrapulmonary location of the object, as indicated by fluoroscopy, was confirmed by operation, at which it was removed through a simple incision over the ninth interspace.

A combination of fluoroscopic examination and pneumothorax also settled the location of foreign bodies lying partly in the extrapleural tissue and partly intrapleurally. This was a particularly important variety of retained object

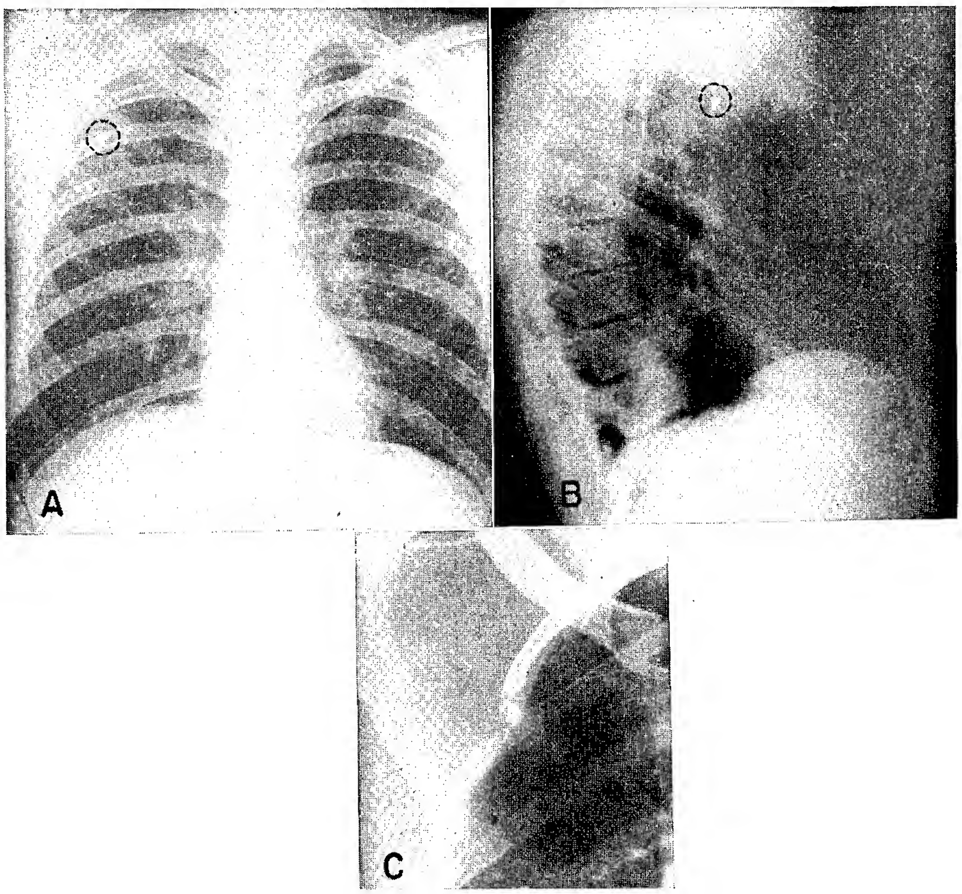

FIGURE 132 (case 8).—Localization of foreign body in chest wall. A. Posteroanterior roentgenogram showing missile in undetermined position. B. Lateral roentgenogram, which is also indeterminate. C. Roentgenogram taken after rotation of patient to bring foreign body to profile position. It is now seen to lie in the thoracic wall.

(p. 326). In the following case, the development of a hemopneumothorax served the purpose of an artificial pneumothorax and clarified the position of the fragment:

Case 10.—This patient was wounded by a penetrating high explosive fragment. Posteroanterior and lateral roentgenograms showed it lying in sector B–B′. Since it was quite large, it was thought that accurate localization might be difficult. Later, when the patient developed a hemopneumothorax, the definite rotation of the object (fig. 135) showed that it must be within lung tissue.

The diagnosis was confirmed at operation.

Pneumothorax was never instituted until a competent thoracic surgeon or other medical officer had stated that it could safely be used. Lung puncture and hemorrhage were always possibilities. The use of this method was limited.

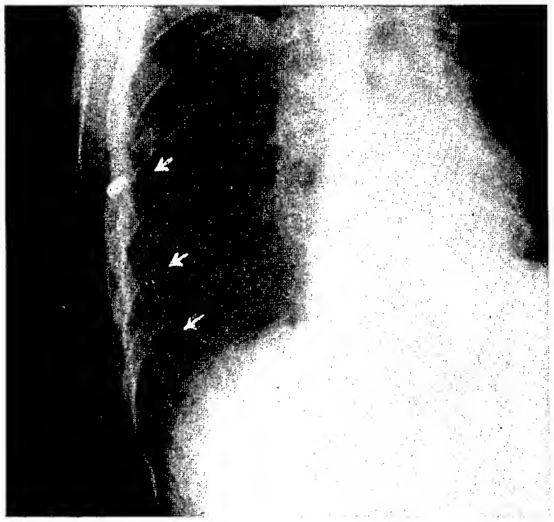

FIGURE 133.—Localization of foreign body in chest wall. Posteroanterior roentgenogram after small artificial pneumothorax. In this case, both plain roentgenography and fluoroscopy had failed to localize the object.

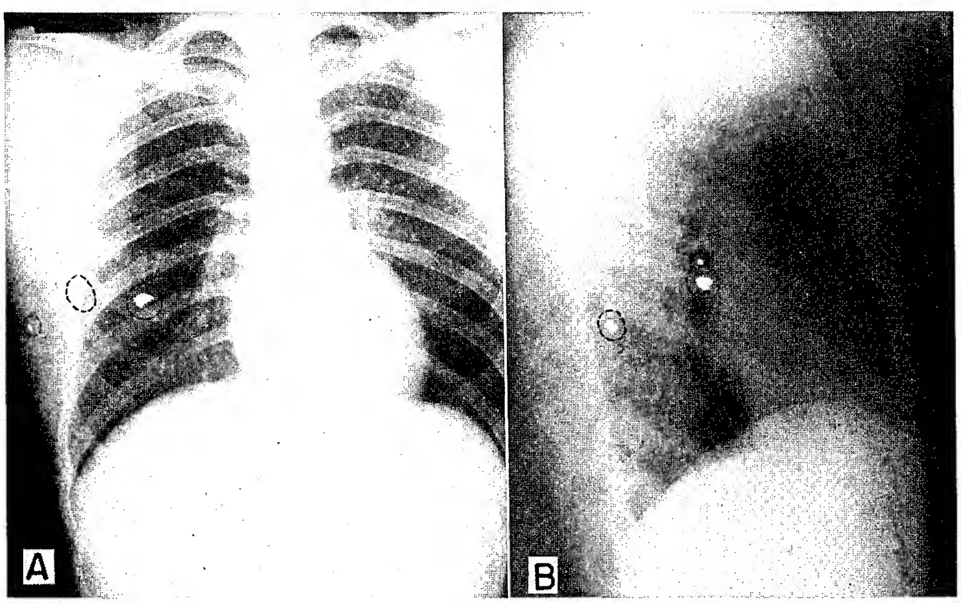

FIGURE 134 (case 9).—Localization of foreign bodies in chest wall. A. Posteroanterior roentgenogram showing two objects in soft tissues of lower lateral chest wall and a third possibly within the lung parenchyma. B. Lateral roentgenogram showing the position of the third fragment was not altered by diagnostic pneumothorax. It was removed at operation by a simple incision over the ninth interspace.

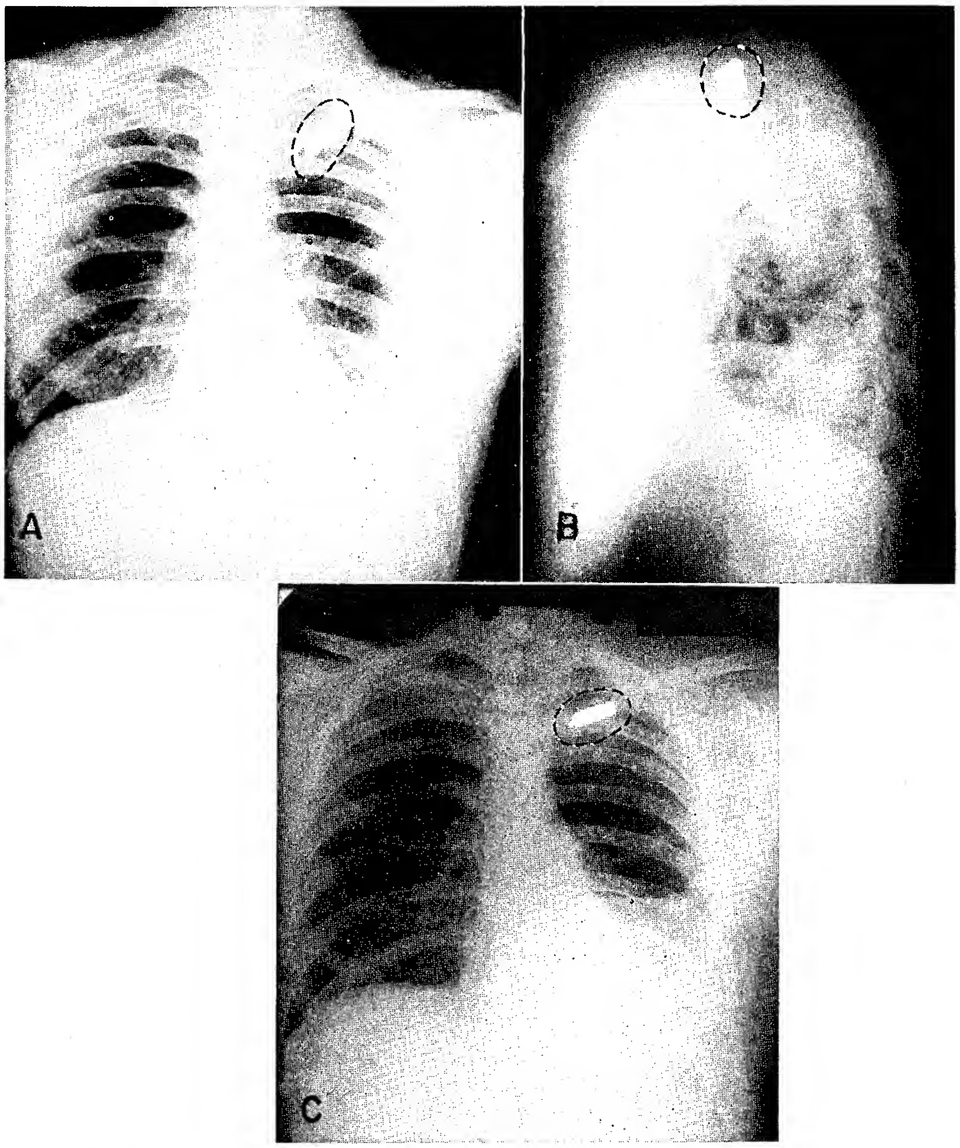

FIGURE 135 (case 10).—Localization of foreign body in lung. A. Posteroanterior roentgenogram showing foreign body in indeterminate position. B. Lateral roentgenogram. C. Posteroanterior roentgenogram showing change in position of foreign body with development of hemopneumothorax.

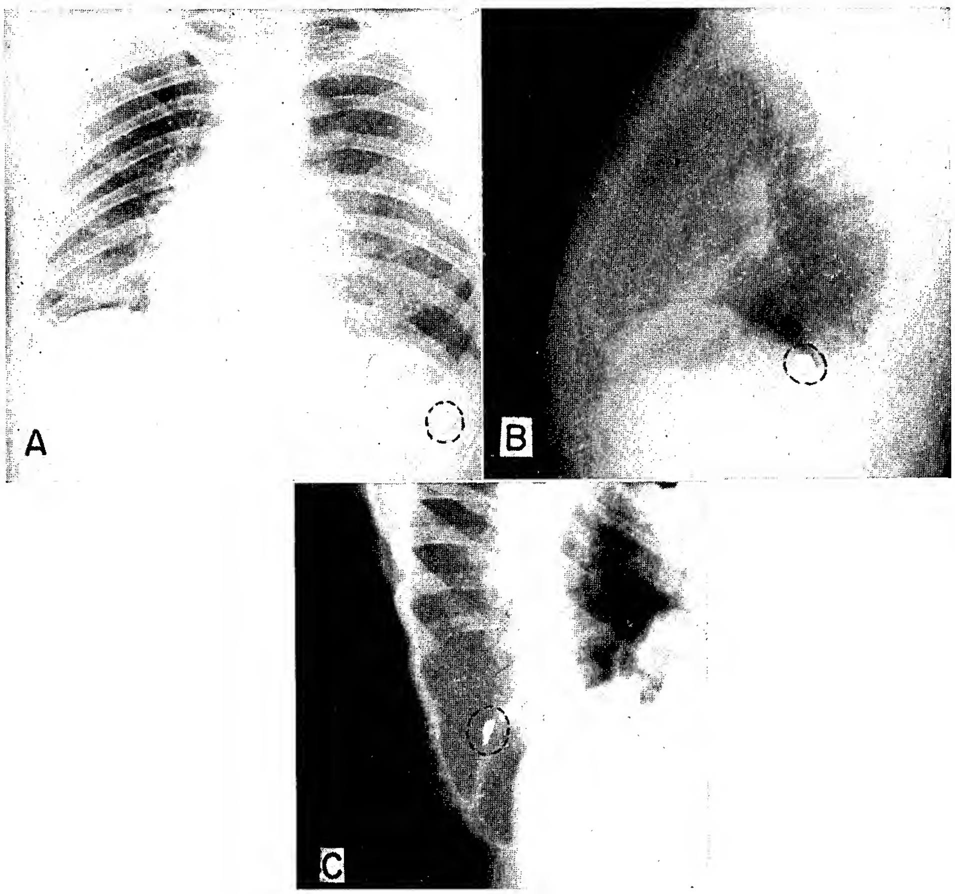

FIGURE 136.—Localization of foreign body in diaphragm. A. Posteroanterior roentgenogram of chest and upper abdomen. B. Left lateral roentgenogram. C. Oblique view after induction of artificial pneumoperitoneum. The diaphragm is shown in profile in this film, and the foreign body is clearly seen embedded in it. The localization was found correct at operation.

A special technique was required, in which relatively few medical officers were trained, because of the decreasing use of pneumothorax in the treatment of tuberculosis.

Diagnostic pneumoperitoneum.—Foreign bodies about the diaphragm were notoriously difficult to localize. It was frequently necessary to induce a diagnostic pneumoperitoneum to establish their exact location (figs. 136, 137, and 138). Once it had been induced, posteroanterior and lateral films were made in the upright position, sometimes supplemented by oblique films and films in the lateral decubitus. If these studies produced even a single view showing

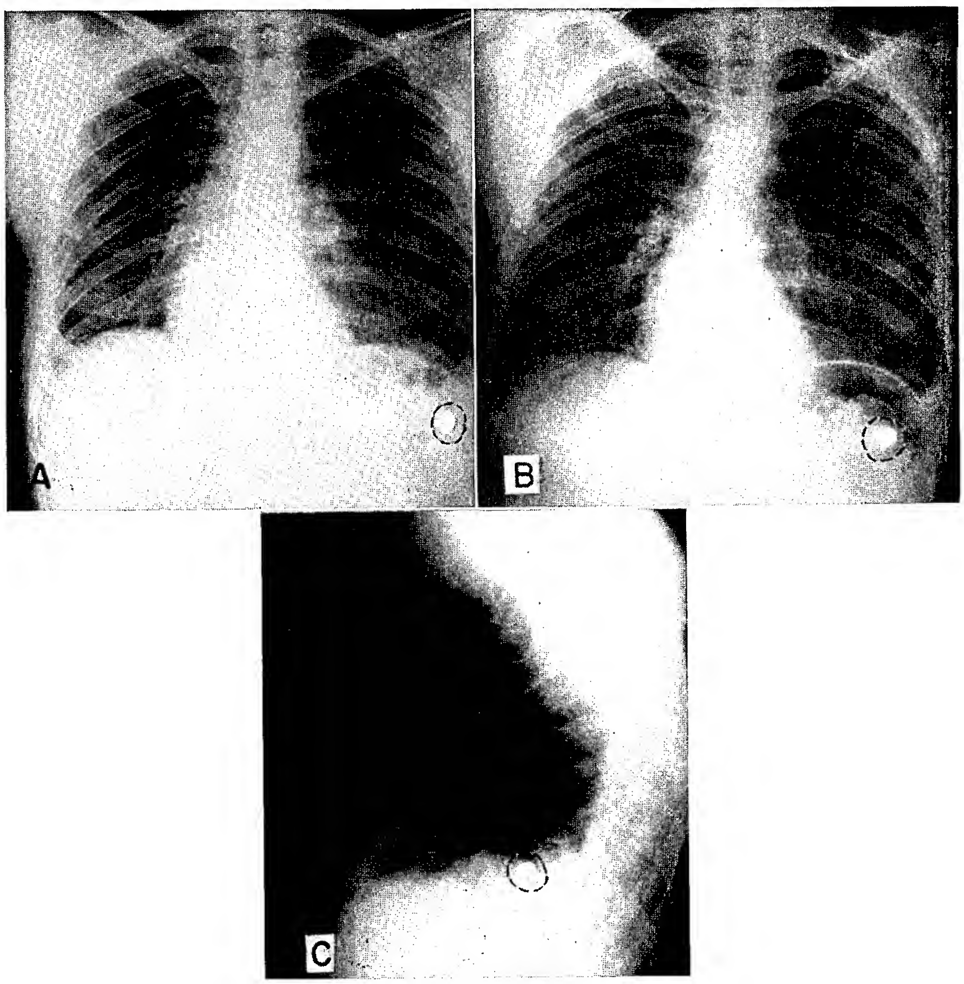

FIGURE 137 (case 11).—Localization of foreign body in diaphragm. A. Posteroanterior roentgenogram showing foreign body in vicinity of diaphragm. B. Posteroanterior roentgenogram after pneumoperitoneum showing object possibly in abdomen. C. Lateral roentgenogram showing foreign body in diaphragm.

the foreign body above the diaphragm, it was evident that the location was intrathoracic and not subdiaphragmatic, as the following cases show:

Case 11.—This patient sustained a wound of the left chest from a high explosive fragment. Posteroanterior and lateral views (fig. 137) showed it lying in sectors A–B′, in the vicinity of the diaphragm, a location in which accurate localization was always more difficult. After pneumoperitoneum had been induced, additional films left the location still undecided. A third film (fig. 137C) definitely located the object in the superior substance of the diaphragm.

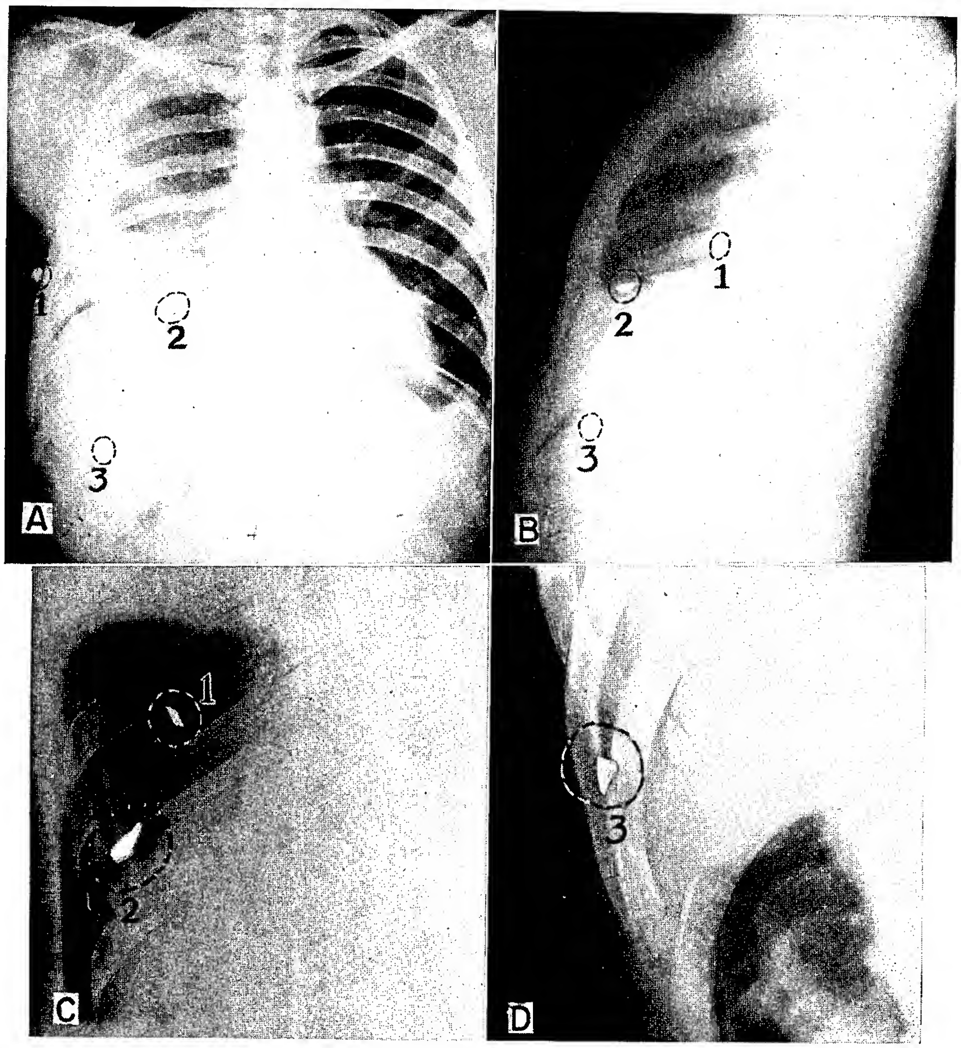

FIGURE 138 (case 12).—Localization of foreign bodies. A. Posteroanterior roentgenogram showing three foreign bodies in right chest (No. 1 extrapleural, No. 2 in undetermined location, No. 3 in abdomen). B. Lateral roentgenogram showing same positions. C. Profile roentgenogram after pneumoperitoneum. Object No. 2 in this film is seen projected in the lung tissue; at operation, it was found in the middle lobe of the lung. D. Oblique roentgenogram showing right costal margin. In this view, object No. 3 lies outside the substance of the liver.

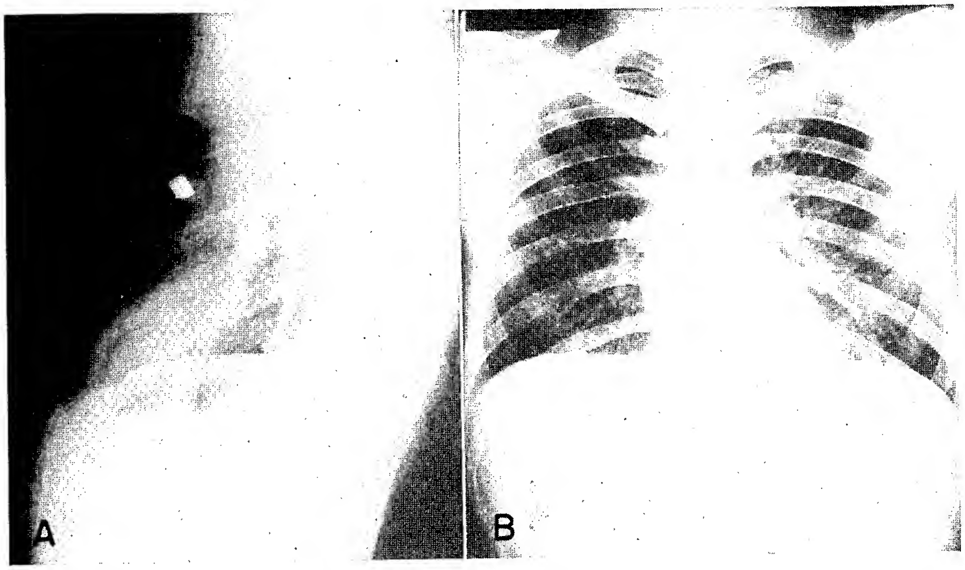

FIGURE 139.—Localization of foreign body in mediastinum. A. Lateral roentgenogram showing foreign body in mediastinum. At operation, it was found to be associated with abscess formation. B. Posteroanterior roentgenogram 2 weeks after thoracotomy, removal of object, and evacuation of abscess. Recovery was uncomplicated, without mediastinal or pleural complications.

In this case, as in a number of similar cases, the oblique view was decisive.

Case 12.—In this case, as in the preceding case, it was necessary to induce pneumoperitoneum to secure exact localization of three foreign bodies (fig. 138). Posteroanterior and lateral films showed one object to be extrapleural, lying in the soft tissues of the chest wall. The second object lay in the anterior costophrenic region above the diaphragm, though whether it was intrapulmonary or intrapleural was not clear. A profile view (fig. 138C) projected the missile in lung tissue, thus proving that it did not lie in the intercostal soft tissues. A third object lay outside the substance of the liver (fig. 138D).

At thoracotomy, the second object was found lying in the substance of the middle lobe of the lung.

Pneumoperitoneum, like pneumothorax, had to be used with care and judgment. It was never employed in the presence of intra-abdominal infection. If abdominal surgery had been performed recently, satisfactory air caps, because of adhesions, were not usually seen over and around the liver. If the object was on the left side, a 2-gm. dose of sodium bicarbonate given orally 15 minutes before the films were made frequently produced enough gaseous distention for a satisfactory outline of the left diaphragm. In an occasional case, both pneumothorax and pneumoperitoneum had to be employed diagnostically to achieve definitive localization of the object.

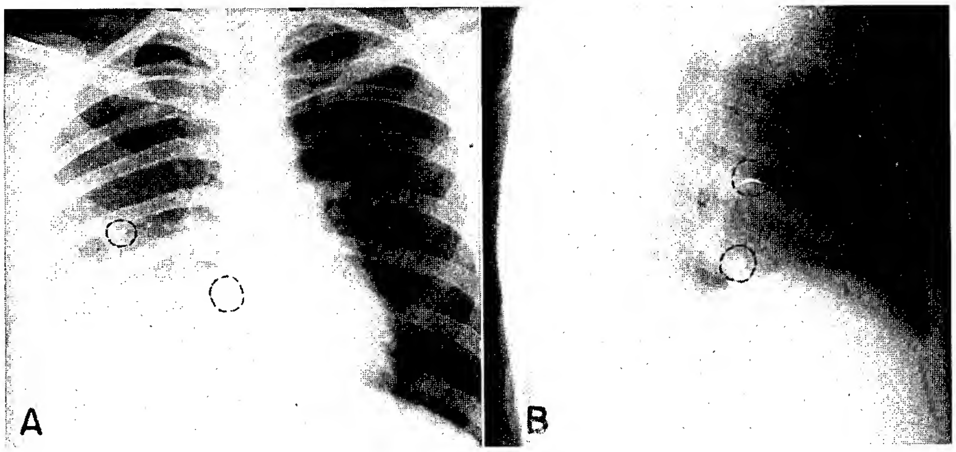

FIGURE 140 (case 13).—Localization of foreign bodies in lung and mediastinum. A. Posteroanterior roentgenogram showing one foreign body in lung and other either in lung or mediastinal tissue. B. Lateral roentgenogram showing same indeterminate location of second object. At operation, it was found just under the mediastinal pleura.

Localization of mediastinal foreign bodies.—Mediastinal foreign bodies sometimes offered difficulties of localization (figs. 139 and 140). They were most often found in sector C–B′ and in this location were frequently observed to move synchronously with the cardiac pulsations. On the left side, in this location, they might be either cardiac or pericardial problems. Differential diagnosis required careful study and consideration:

Case 13.—This patient received multiple wounds of the extremities and the right side of the chest when a shell exploded close to him. Examination of the posteroanterior film (fig. 140A) showed two foreign bodies. The first lay in sector B–B′ and was clearly in the intrapulmonary substance. The second lay in sector C–B′, which made it necessary again to differentiate between an intrapulmonary and a mediastinal location.

At operation, the second object was found in the mediastinum, just under the mediastinal pleura.

The evaluation of mediastinal foreign bodies was also important from another standpoint, the possibility of injury of the esophagus. If this suspicion existed, operation was a matter of extreme urgency. Overlooked esophageal perforations were attended with a very high mortality. Moreover, the surgical approach was different from that employed in the removal of intrapleural, intrapulmonary, and other mediastinal foreign bodies. Patients were questioned explicitly concerning any symptoms which might point to esophageal injury, particularly dysphagia.

It was difficult to differentiate some intrapulmonary missiles from missiles located in the mediastinum, but, since the surgical approach was the same in both instances, the differentiation was academic rather than practical.

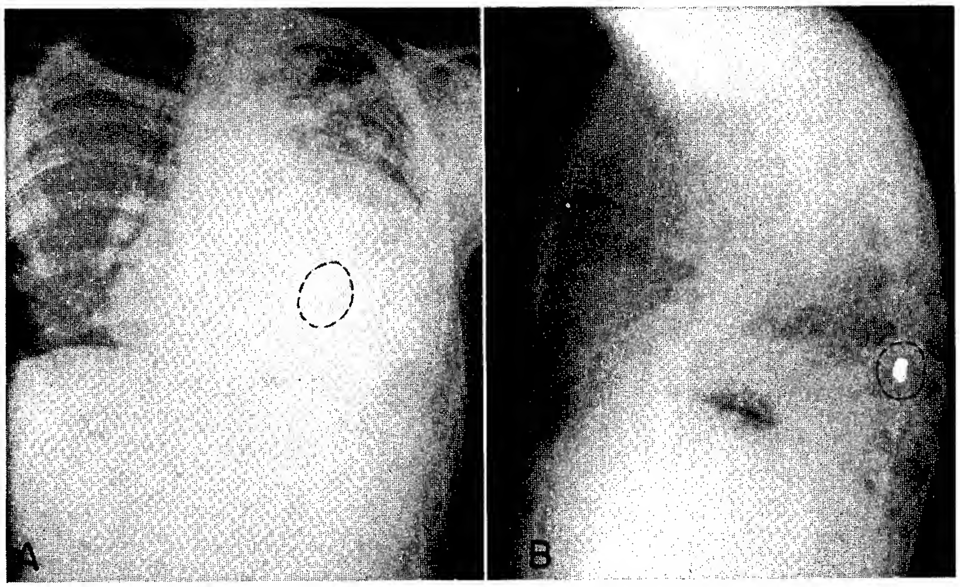

FIGURE 141.—Localization of foreign body in intrapleural space. A. Posteroanterior roentgenogram showing object in either intrapleural or intrapulmonary location. B. Lateral roentgenogram, which also does not differentiate the position. At operation, the object was found free in the intrapleural space. In this case, clotted hemothorax prevented the use of diagnostic pneumothorax.

SURGICAL TECHNIQUE

The fundamental surgical principle of adequate exposure was particularly important in the removal of foreign bodies from the lungs. Skin and muscle incisions had to be wide enough to permit access to at least two interspaces when the bony thoracic cage was exposed. If precise localization had been accomplished and if the lung was adherent to the chest wall, it was sometimes possible to remove the object without entering the free pleural space.

When the object was deeply embedded in the lung, an opening into the pleura was necessary and had to be large enough to permit palpation and adequate exposure.

A posterior incision was usually employed, without division or resection of the ribs. A short incision was made into the lung, at the point at which localization procedures, confirmed by palpation, had indicated that the foreign body was nearest the surface. When operation was performed soon after wounding (within 14 days), there was, as a rule, little or no reaction about it.

Localization was sometimes less accurate than desirable because the presence of a clotted pneumothorax prevented the use of diagnostic pneumothorax (fig. 141). Hemothorax or hemothoracic empyema sometimes complicated the situation at operation also. Decortication, in some cases, had to be carried out before a search for the object was undertaken, as it was not possible to palpate a

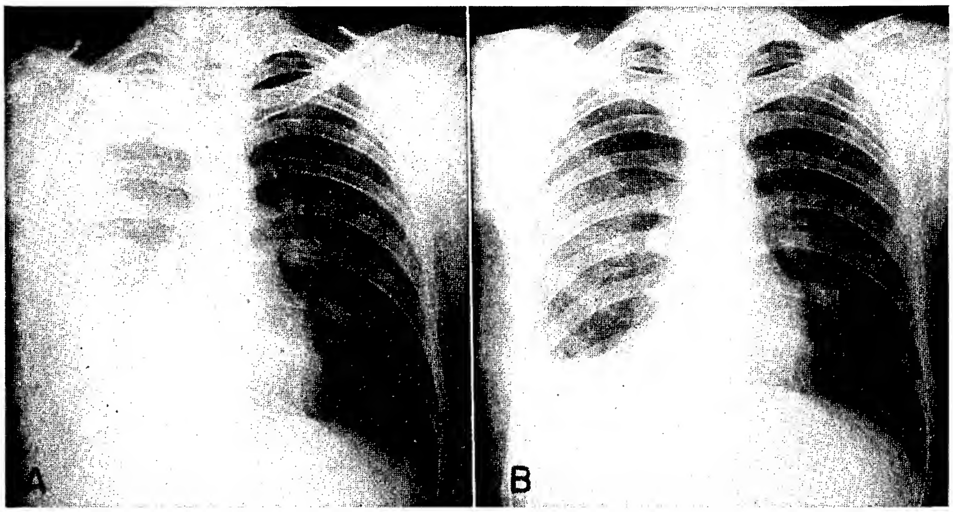

FIGURE 142 (case 14).—Intrapleural foreign body associated with massive empyema. A. Posteroanterior roentgenogram showing intrapleural metallic object (arrow) with associated clotted hemothorax, which went on to massive hemothoracic empyema. B. Same, 10 days after removal of foreign body and decortication of lung. Recovery was complete.

fragment through the inelastic rind. If the hemothorax involved only a single lobe, decortication was also preferable to an extended and difficult search for the foreign body. Associated abscesses were either curetted out or, if the lesion was peripheral, were managed by wedge resection.

Closure was by the silk technique throughout. The lung was closed in two layers, the pleura being inverted with the second layer. Sutures were placed in the intercostal muscles and tied after the ribs had been approximated. Pericostal sutures were avoided.

The chest was ordinarily drained with both anterior and posterior intercostal water-seal tubes. The use of the anterior tube, which was usually removed within 48 hours, insured prompt expansion of the upper lung. The posterior tube was kept in place for 3 or 4 days.

In the early experience, penicillin was used intrapleurally, but this practice was subsequently discarded, and the antibiotic was used systemically before and after operation.

The following case history illustrates the successful management of foreign bodies associated with massive empyema:

Case 14.—This patient was struck in the right chest by a bomb fragment on 26 March 1944, sustaining a severe penetrating wound, with hemothorax. A metallic foreign body was retained in the affected area.

The wound was debrided, and repeated aspiration was employed. This procedure, at first effective, later ceased to be useful, and the patient developed fever and other symptoms and signs of sepsis. Roentgenograms revealed a right clotted hemothorax in addition to the retained foreign body (fig. 142A). Material aspirated from the right chest became

progressively more purulent and more offensive in odor. Cultures grew proteolytic clostridia.

Under penicillin protection, a thoracotomy was done 21 days after injury, with removal of the foreign object and decortication of the lung.

Recovery was prompt and uneventful (fig. 142B). The patient was discharged to full duty on 5 June 1944, about 10 weeks after injury.

ANALYSIS OF CASES

In a series of 1,058 penetrating wounds of the chest observed by surgeons of the 2d Auxiliary Surgical Group in the Mediterranean theater, an experience which may be assumed to be typical, there were 291 retained intrathoracic foreign bodies, exclusive of foreign bodies in the heart and pericardium. Of these, 39 were intrapleural and 252 intrapulmonary and mediastinal. Since the great majority of these patients were under observation in thoracic surgery centers for periods ranging from a week to 2 months after injury, this series offered an excellent opportunity to determine what happens to retained intrathoracic missiles within this period after wounding.

Preoperative Complications

The following complications, which developed during the periods of observation, represent the ill effects of retained foreign bodies:

In the 252 intrapulmonary and mediastinal foreign bodies, there were 4 delayed or recurrent hemoptyses; 2 secondary intrapleural hemorrhages from the lung; 18 late or recurrent bronchopleural fistulas; 4 lung abscesses; 2 mediastinal abscesses associated with the retained objects; and 30 empyemas.

In the 39 intrapleural foreign bodies, there were 15 empyemas.

The total complications in these 291 cases were thus 75 in number, 25.8 percent; 60 were associated with the 252 intrapulmonary and mediastinal objects and 15 with the 39 intrapleural objects.

There was no correlation in this study between the incidence of complications and the size and configuration of the missiles. There was also no correlation as to location except in one regard, that missiles located in the periphery of the lung gave rise to a higher incidence of complications than those in the hilus. This observation was at variance with the popular concept that a missile lying in close proximity to vascular or bronchial structures in the hilus was more likely to give rise to complications than a missile in the periphery. The explanation may be that missiles that lodged at or near the hilus were missiles that had lost their momentum. Those that tore through it usually lacerated the major divisions of the pulmonary artery or vein, with rapid death by exsanguination. Surgeons who worked in field hospitals almost never saw a casualty with damage to a major pulmonary vessel. These casualties did not live long enough to be hospitalized.

These figures are significant in view of the numerous discussions concerning the relative incidence of empyema in intrapleural versus intrapulmonary retained foreign bodies. In the 39 intrapleural cases, empyema occurred 15 times, an incidence of 38.5 percent. In the intrapulmonary group of 252 objects it occurred 30 times, an incidence of 11.9 percent, which is strikingly close to the overall incidence of empyema in chest wounds in the Mediterranean theater. This observation corroborated the opinion generally held by thoracic surgeons that intrapleural foreign bodies were far more likely to give rise to trouble than intrapulmonary missiles.

The majority of the complications, almost 75 percent, developed during the second and third weeks after injury. Aside from the empyemas, the earliest complication observed was a lung abscess which appeared a week after injury. Only 4 complications, none in the intrapleural group, developed earlier than 10 days after wounding. The earliest complications were usually hemorrhage, atelectasis, pneumonitis, and pulmonary embolus. Lung abscess was extremely uncommon (at all times), though in this series it was the first complication to be observed, 7 days after wounding.

Results of Surgery

Surgery was carried out in 102 of these 291 retained foreign bodies, in 15 instances for intrapleural objects and in 87 for objects in the intrapulmonary or mediastinal tissues (fig. 143). In five instances, the object was not removed, for various reasons, and in four instances, it was not found at the site expected from the preoperative localization.

There were no deaths in the 102 operations and no instances of permanent disability or deformity. The 13 postoperative complications were distributed as follows: 3 wound infections; 4 empyemas (3 small, resulting from subjacent extension of the wound infection to the pleural cavity and 1 basal, unrelated to wound infection); 1 clotted hemothorax; 1 atelectasis; 1 secondary hemorrhage; 2 bronchopleural fistulas; and 1 thrombophlebitis. None of these complications resulted in prolonged disability.

About half of the retained objects, as previously mentioned, were found with associated cloth fragments at the site of lodgment, but, except in the four lung abscesses, no positive cultures were obtained from the missile cavities.

Conclusions

Although the series is small, these figures are important, since they overturn many misconceptions as to the innocuousness of retained intrathoracic missiles. An incidence of 15 percent of significant complications within the first 60 days after wounding points to the fact that the retained missile is, on the contrary, a real source of danger to the host and must be considered seriously in the reparative management of every case. On the other hand, the fact that so few complications developed earlier than 10 days after wounding justified

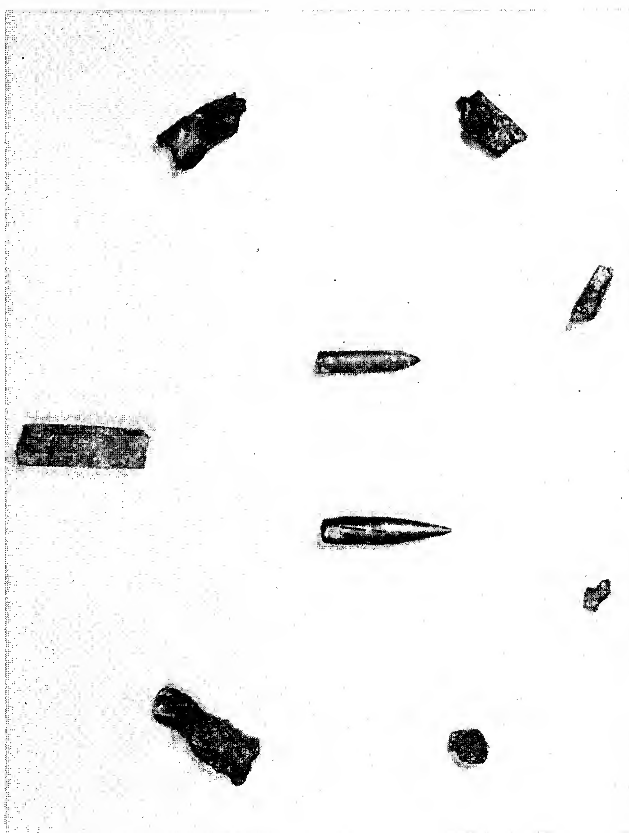

FIGURE 143.—Specimens of metallic foreign bodies removed from lungs and pleural cavity.

the policy of waiting until the patient had arrived in a fixed hospital to remove the missile.

This comparison definitely favors the removal of retained foreign bodies, though not statistically. The incidence of postoperative complications, when surgery was done at the thoracic surgery center in this series was approximately 13.4 percent, while the incidence of complications encountered when the foreign bodies were not removed was 15 percent. Statistically, this is a totally insignificant difference, almost an argument, in fact, for leaving these objects in situ. Clinically, however, the balance is all in favor of their removal at the proper time and on the proper indications. The complications of retained foreign bodies are all debilitating, and many of them are potentially fatal. The properly staged removal of these objects, however, is attended with a minimal mortality—there were no deaths in this series—and with a low morbidity.

Much remains to be learned concerning the question of retained foreign bodies in penetrating thoracic wounds. This analysis of a small series of cases

is not conclusive, and final statistics are not yet available. The analysis, however, does show the fallacy of the opinion that it can be confidently anticipated that such objects will do no harm, and it also vindicates the Mediterranean theater policy of removing all objects larger than 1.5 cm. in their greatest diameter, preferably within the first 14 days after injury, after the patient has been evacuated to the base.

Final appraisal must await long-term followup studies on both the group in which the object was retained and the group in which it was removed.[3]

[3] The reader is referred to chapter XI (p. 441) for long-term followup studies on casualties with retained foreign bodies in the chest.

CHAPTER VIII

Management of Retained Foreign Bodies in the Heart and Great Vessels, European Theater of Operations

Dwight E. Harken, M.D.

ANATOMIC LOCATION OF MISSILES

Over a 10-month period in World War II, thoracic surgeons working in the thoracic surgery center set up in the 160th General Hospital, 15th Hospital Center, Cirencester, Gloucestershire, European Theater of Operations, U.S. Army, performed 134 operations for the removal of missiles retained in and about the heart and great vessls. There were no deaths in the series, and all patients were discharged with normally functioning hearts.

The experience of World War II confirmed the difficulty, commented upon elsewhere, of accurate localization of metallic foreign bodies in relation to wounds of the heart. In about half of the patients referred to the chest service at the 160th General Hospital as harboring foreign bodies within the heart, the objects were found, after careful fluoroscopic examination, to be extracardiac. Furthermore, early in the experience on this service, it was found at operation that about a third of the fragments thought to be intracardiac were extracardiac. Even on exploration, it was not always easy to determine whether an object lay within the pericardium or within the auricle; this was particularly true if an infected hematoma was present.

The location of the 134 foreign bodies in this series, as proved by operation, was as follows (fig. 144):

Of the 56 foreign bodies in and about the heart, 13 were intracardiac, 26 were entirely within the pericardium, and 17 partly within the pericardium but chiefly within the lung. Of the 13 foreign bodies removed from the chambers of the heart (fig. 145), 7 were in the right ventricle, 4 in the right auricle, 1 in the left ventricle, and 1 in the left auricle.

The great vessels were involved, directly or indirectly, in 78 cases. In seven instances, the missiles were intravascular; the three of these which became embolic are discussed in detail elsewhere (p. 380). In 35 instances, the fragments lay on the great vessels or within the vascular walls. In 17 cases, they were directly adjacent to the vessels but were chiefly within the lung. In 19

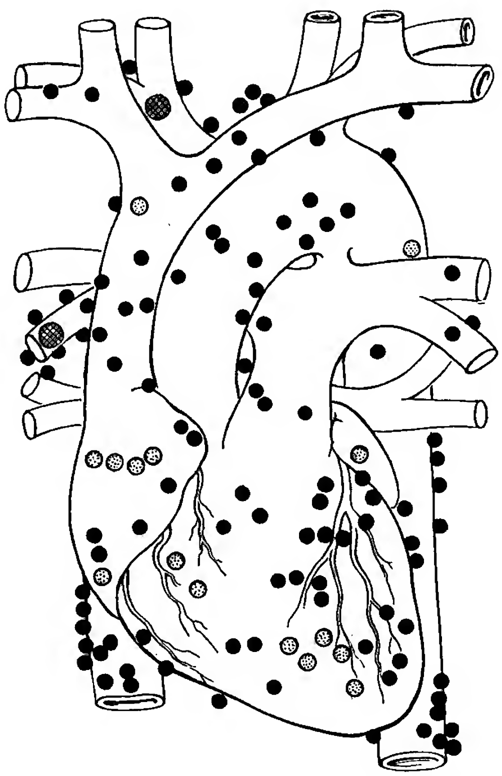

FIGURE 144.—Gross location of foreign bodies removed from cardiac and vascular structures at 160th General Hospital. Stippled: missiles impinging on structures. Black: intra-structural missiles. Crosshatching: embolic missiles.

instances, they were within the mediastinum but were not in direct proximity to the great vessels.

The fact that no missiles were encountered within the lumen of the thoracic aorta and that in only one instance was a missile found in the left ventricle seems to warrant the assumption that the direct entrance of foreign bodies of any considerable size into either of these areas was seldom compatible with survival. The anatomic distribution of these missiles suggests further that fragments small enough to enter the left ventricle as migratory foreign bodies were probably swept out of it by the high systemic pressure, in contrast to those which entered the right ventricle, where physiologic circumstances were more favorable for their lodgment.

Over the same 10-month period during which these 134 successful operations were performed, 4 unsuccessful operations were undertaken for the removal of foreign bodies in and near the heart. In two instances, the missiles

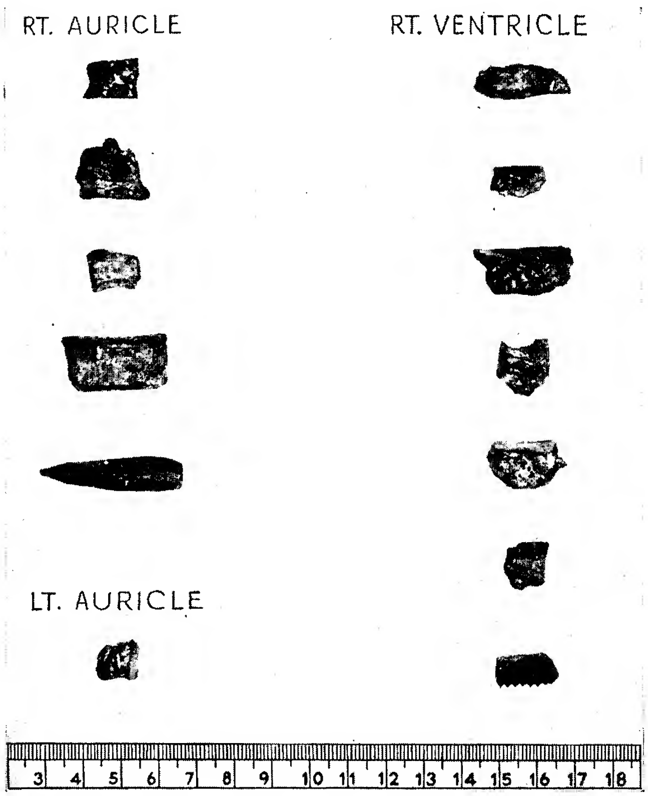

FIGURE 145.—Missiles removed from chambers of heart, with their location.

could not be recovered at cardiotomy, and in the other two instances, exploratory pericardiotomy revealed that their removal would have been attended with unjustifiable risks.

In 15 other patients in whom foreign bodies in or about the heart were encountered, operation was not undertaken, for one reason or another, and the objects were permitted to remain in situ.

FOREIGN BODIES IN AND ABOUT THE HEART

Indications for Surgery

The diagnostic confusion, already mentioned, of determining whether a retained missile was or was not within the heart added to the difficulties of assessing the risk to life and health of retained intracardiac missiles. In spite of numerous isolated reports of foreign bodies which have lodged in the heart

and remained asymptomatic, there is also considerable evidence in the medical literature that these objects may be lethal. Experimental evidence, furthermore, suggests that their presence may give rise to bacterial endocarditis.

As the war progressed, therefore, a working policy for the management of intracardiac missiles was formulated from the medical literature, from a limited amount of experimental work previously done on animals, and from the individual surgeons' own concepts and their accumulating experience. Although the policy was originally based upon somewhat uncertain premises, it was substantiated by the clinical evidence secured in the various chest centers in the European theater during the course of the war.

The indications for the removal of foreign bodies in and about the heart were chiefly based on possible risks, which included embolism, bacterial endocarditis, recurrent pericardial effusions, and myocardial damage. The development of symptoms and the existence of cardiac neurosis also served as indications.

The risk of embolism.—The development of embolism from a foreign body or from the thrombus associated with it was not merely a theoretical possibility. Several such accidents had been recorded in the prewar literature, and at least two are known to have occurred in the European theater during World War II. One of these cases is included in the series analyzed in this chapter. The missile lay in the interauricular septum and right auricle and was removed from the auricle; the thrombus was found in the left auricle. Hemiplegia occurred in this case soon after wounding. In the second case, reported by Lt. Col. Arthur D. Nichol, MC, the embolism arose from a missile in the left ventricle. It is significant that the hemiplegia which followed it appeared more than 2 weeks after wounding.

The risk of infection.—The removal of retained intracardiac objects because of risk of the development of bacterial endocarditis was, as already intimated, partly based on the results of experimental work on dogs. The implantation of foreign bodies in various locations in the heart was followed by the development of bacterial endocarditis characterized by typical bacterial valvulitis and of septic embolic infarcts. The experimental evidence was limited, but it was naturally feared that foreign bodies retained in the human heart might give rise to the same consequences.

Clinical support for this hypothesis was confined in this series to a single case: The patient ran a course suggestive of subacute bacterial endocarditis, with spiking fever, tachycardia, and one acute episode of pain in the right upper quadrant associated with jaundice. Response to surgical removal of the missile and the attached thrombus from the right auricle was immediate and dramatic. Although the patient was almost moribund when operation was undertaken, his recovery was prompt and uncomplicated.

The bacteriologic support for the indication of infection in this series of cases is somewhat more conclusive. No cultural studies were made in 4 of the 13 intracardiac foreign bodies. There was growth of bacteria on cultures made from only one of the five fragments removed from within the right ventricle; this particular foreign body lay in an abscess within a mural thrombus in the ventricular chamber. Cultures were also positive for pathogenic organisms in three of the four cases in which foreign bodies were removed from within the auricle. One of these missiles was found in a small abscess in the center of a mural thrombus in the right auricle.

It cannot be said positively that the infected niduses in these cases represented true bacterial endocarditis, nor can it be said that the infections present would eventually have produced it. Nonetheless, the findings seemed to furnish further support for the removal of intracardiac missiles because of the possible development of infection.

The risk of recurrent pericardial effusions.—The risk of recurrent pericardial effusion as an indication for the removal of intracardiac foreign bodies has been repeatedly stressed in the medical literature and is well established. On the other hand, in the only two instances of pericardial effusion observed at the 160th General Hospital, the symptoms were not severe enough, and the fragments were not large enough, to justify surgical intervention.

The risk of myocardial damage.—Myocardial damage was clearly evident in three cases in this series. The damage to the right ventricular wall overlying the site of a migratory missile noted in the following case seems of special significance in several respects. In particular, it demonstrates that the mere presence of a foreign body in a cardiac chamber can produce considerable damage to the overlying myocardium in a period of 3 months, and it also indicates that surgical removal of the object does not, of itself, cause myocardial injury of any consequence:

Case 1.—A 29-year-old infantry sergeant was injured in the right lower posterior chest on 21 July 1944, in the fighting about Saint-Lô. Fluoroscopic and roentgenologic examination (fig. 146) showed a metallic foreign body lying in the anterior portion of the right ventricle, just to the left of the midline, and pulsating with the heart. An electrocardiogram 4 days later (fig. 147) showed no abnormalities except for inverted T-waves in the right-sided precordial leads (CF_1, CF_2, and CF_3). By 8 August, the T-waves in CF_3 had become upright, and the tracing appeared entirely normal.

First operation.—Operation was performed on 15 August in the dorsal decubitus position (fig. 148). When the missile was grasped through an incision in the right ventricle, it was jerked from the grasp of the forceps by the movements of the myocardium and was lost to both sight and palpation in the bloodstream.

Roentgenograms taken immediately after the operation (fig. 149) showed the missile lying in the right auricle, over the opening of the inferior vena cava. Another electrocardiogram on 17 August (fig. 150) showed elevated ST segments in leads I and II, which fell by 1 September. Later, the T-waves also became sharply inverted in leads I and II and in the left-sided precordial leads CF_4 to CF_6. It was speculated that while this damage

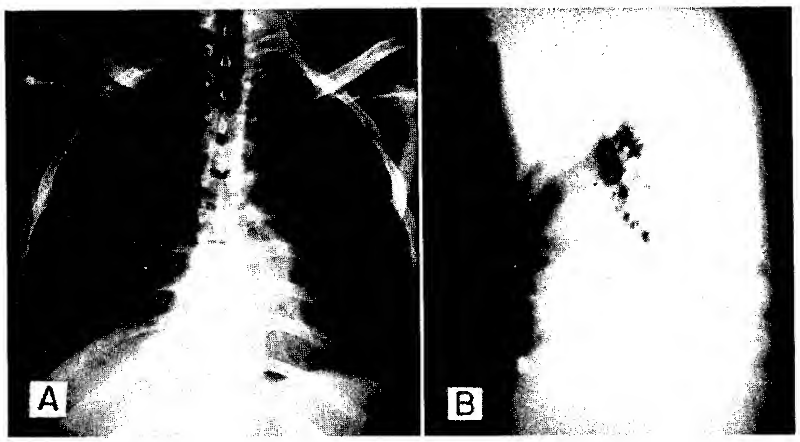

FIGURE 146 (case 1).—Roentgenograms showing original position of fragment in right ventricle. A. Posteroanterior view. B. Lateral view.

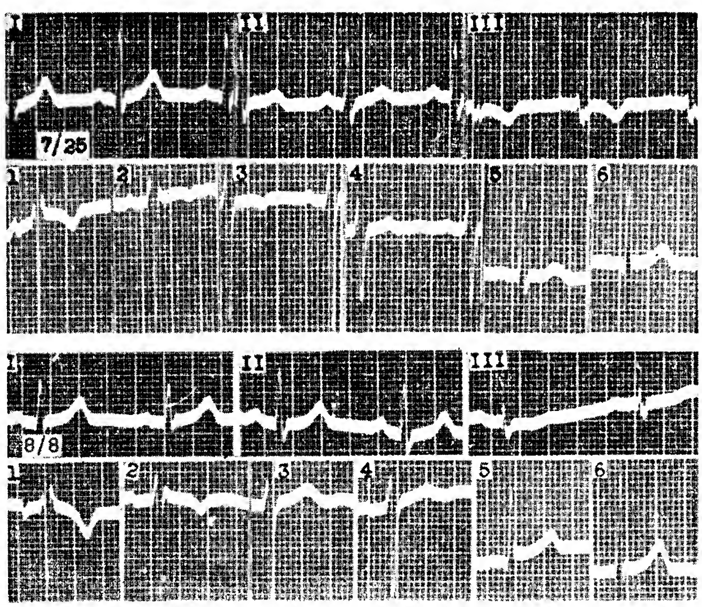

FIGURE 147 (case 1).—Electrocardiograms taken before first cardiotomy. Roman numerals indicate limb leads and Arabic numerals precordial leads CF_1 to CF_6.

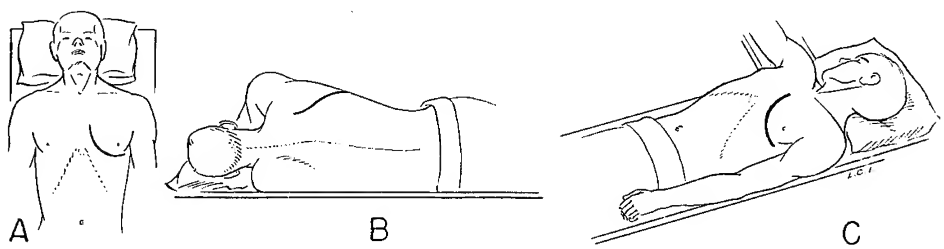

FIGURE 148 (case 1).—Positioning of patient at successive cardiotomies. A. Dorsal decubitus (seen from above). B. Lateral decubitus (right side up). C. Reverse Trendelenburg position with elevation of right side.

might be related to the surgical incision made in the right ventricle near the septum, in the anterior surface of the heart, it might also result from an associated pericarditis.

Second operation.—At a second cardiotomy on 16 November, 3 months after the first, with the patient in lateral decubitus (fig. 148), the missile was visualized and palpated in the right auricle, just above the entrance of the inferior cava. Again it escaped, this time falling back into the right ventricle (fig. 151). Incidentally, a significant diagnostic point is demonstrated by the roentgenograms taken after operation: They were not made in the true lateral position, and the impression was that the missile was in the chest wall. Had these been the first roentgenograms taken, considerable diagnostic confusion might have been caused.

Electrocardiographic examination (fig. 152) showed no specific acute change after the second cardiotomy. There was merely a progressive return toward normal of the T-waves and of leads I and II and CF_5 and CF_6.

Third operation.—On 19 February 1945, at the patient's own request, a third cardiotomy was performed. The anterior approach was used, as in the first operation, but this time the patient was placed in the reverse Trendelenburg position (fig. 148). The scar

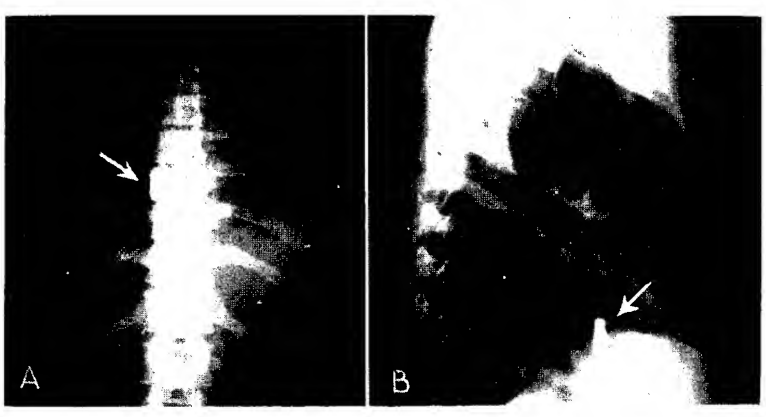

FIGURE 149 (case 1).—Roentgenograms showing position of fragment in right auricle after first (unsuccessful) operation. A. Posteroanterior view. B. Lateral view.

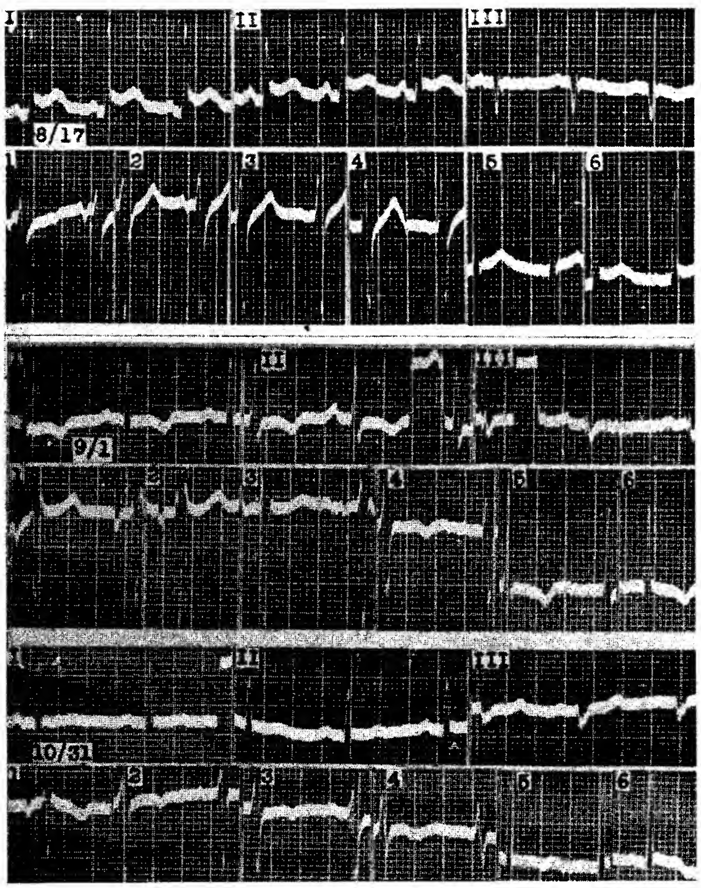

FIGURE 150 (case 1).—Electrocardiograms taken after first (unsuccessful) cardiotomy. See figure 147 for key.

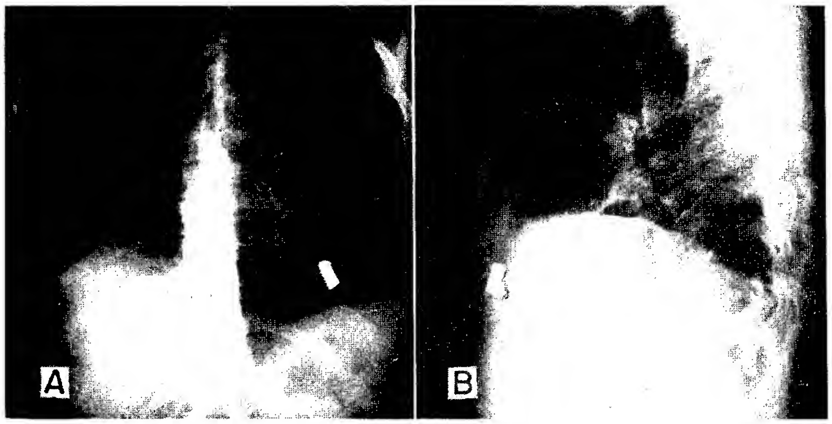

FIGURE 151 (case 1).—Roentgenograms showing fragment again in right ventricle after second (unsuccessful) cardiotomy. A. Posteroanterior view. B. Lateral view.

of the first incision in the right ventricle, made 6 months earlier, was found solidly healed. This was demonstrated visually (plate I) as well as clinically by the colored motion pictures taken at the operation. The considerable fibrous pericarditis that had developed did not limit cardiac motion or obstruct the blood flow. Near the apex of the right ventricle, however, the muscle wall was thin, flabby, and discolored (plate II). The missile was palpable in the right ventricular cavity, just under the area of myocardial damage, which presumably had been produced by the friction of the muscle wall over the fragment during the 3 months after the second operation.

The heart was opened through the area of damage and the shell fragment (fig. 145) was grasped by forceps and was removed with only moderate difficulty (plate III). Intracardial manipulations were carried out in three episodes, over a period of about 3 minutes. Showers of extrasystoles were noted during the removal of the missile (fig. 153).

In spite of the successive migrations of this foreign body (fig. 154), this patient suffered no significant cardiac damage (fig. 155) and was in excellent condition (fig. 156) when he was discharged to the Zone of Interior.

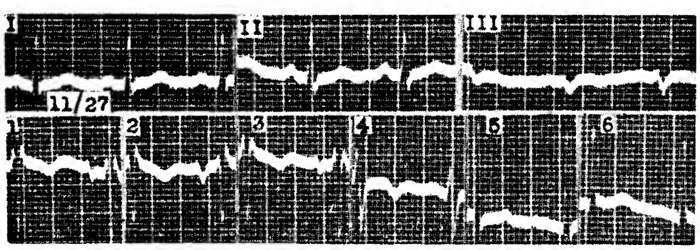

FIGURE 152 (case 1).—Electrocardiogram taken after second (unsuccessful) cardiotomy. See figure 147 for key.

PLATE I (case 1) (right).—Appearance of heart at instant of incision into right ventricle (compare with figure 146A).

PLATE II (case 5) (left, bottom).—Technique of dislocation of heart from pericardial sac.

PLATE III (case 5) (right, bottom).—Marked ventricular dilatation following dislocation of heart. This photograph, like plate II, was taken during the operation. These plates should be compared with the electrocardiographic tracings taken during operation (fig. 173).

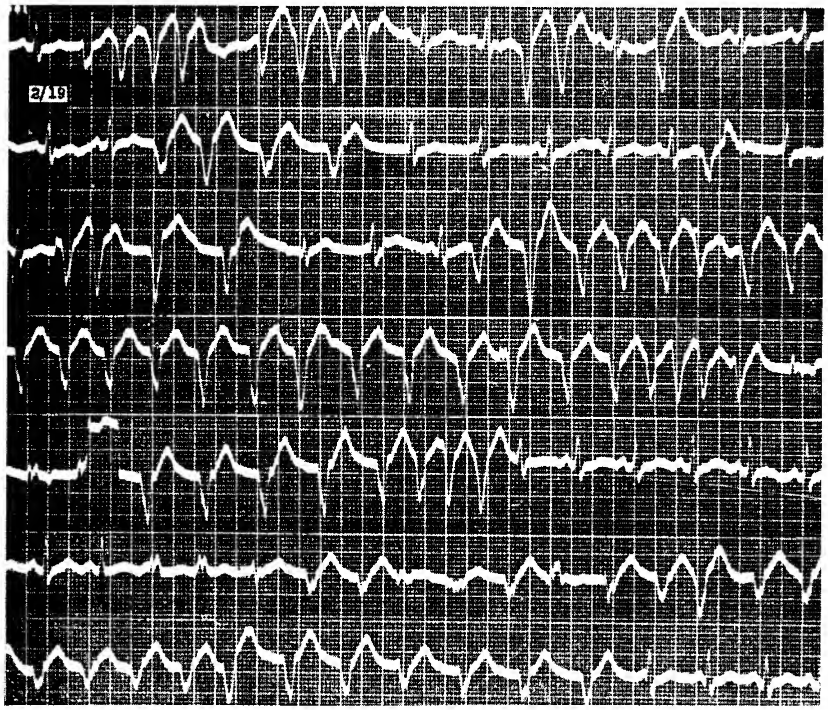

FIGURE 153 (case 1).—Electrocardiograms taken during third and successful cardiotomy at time of removal of fragment from right ventricle. See figure 147 for key.

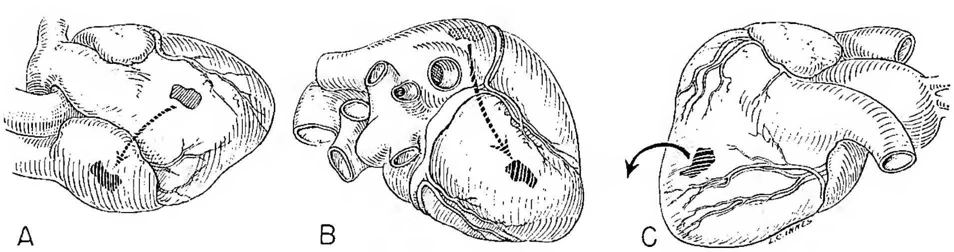

FIGURE 154 (case 1).—Migration of foreign body at successive cardiotomies. A. Movement from right ventricle to right auricle as shown by dotted arrow; first operation in dorsal decubitus. B. Movement from right auricle back to right ventricle; second operation in left lateral decubitus, depicted by dotted arrow. C. Missile in right ventricle at third operation, in reverse Trendelenburg position, with elevation of right side. Solid arrow designates site of successful surgical removal of foreign body through anterior wall of right ventricle.

FIGURE 155 (case 1).—Electrocardiograms taken after third and successful cardiotomy with removal of fragment from right ventricle. See figure 147 for key.

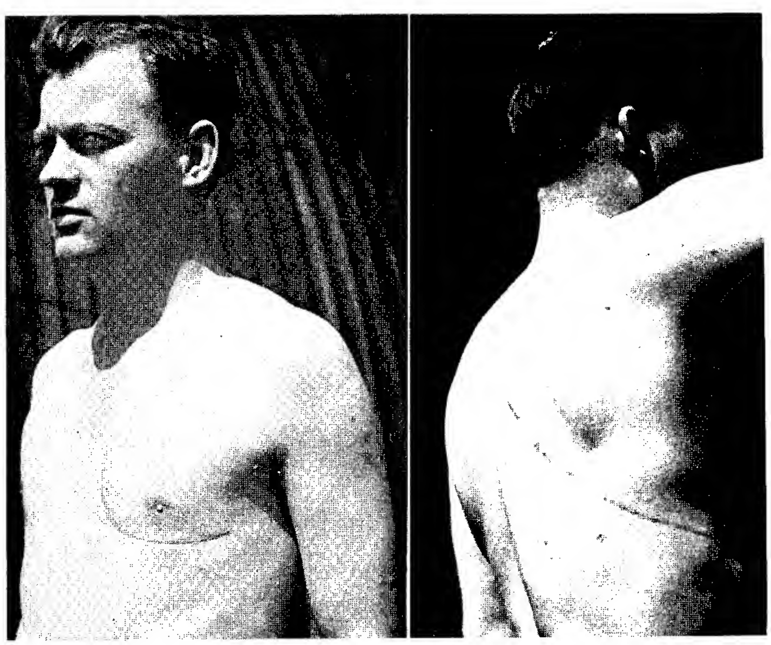

FIGURE 156 (case 1).—Patient just before evacuation to Zone of Interior, after three cardiotomies for removal of retained intracardiac missile.

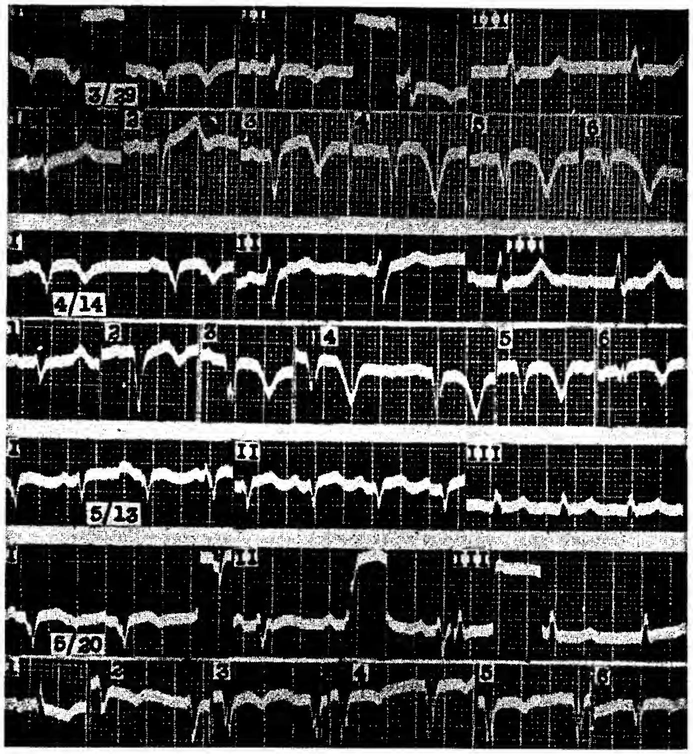

FIGURE 157 (case 2).—Electrocardiograms taken before cardiotomy showing left ventricular damage from retained missile in left ventricle. See figure 147 for key.

Case 2.—Another instance of myocardial damage occurred in the only case in the series in which the foreign body was in the left ventricle. Roentgenokymographic studies showed diminished amplitude of pulsation at the apex and passive left ventricular dilatation during systole, suggestive of an early ventricular aneurysm or hernia. Electrocardiographic studies (fig. 157) showed a persistent pattern characteristic of extensive damage to the anterior left ventricular wall, consisting of low voltage, deep Q_1, absent R_1 and inverted T_1, together with inverted and W-shaped QRS complexes and sharply inverted and coved T-waves in the left-sided precordial leads.

At operation, the foreign body was found in the left ventricle, as the roentgenograms (fig. 158) had shown, in a cystic zone of myocardial damage 1.5 cm. in diameter. It was ballotable in the defect in the cardiac wall, and parodoxical pulsation of this area of the ventricle was noted. A mural thrombus, which was not disturbed, permitted removal of the missile without hemorrhage. The myocardial defect, after closure, was covered over with two superimposed pericardial grafts.

In this case, electrocardiographic tracings taken at frequent intervals during the operation showed no evidence of cardiac irritability at any time except for a few ventricular extrasystoles during the process of endotracheal intubation. It was believed that removal of the missile and repair of the myocardial defect prevented progression of the myocardial damage and averted possible rupture of the heart. Direct inspection at operation left no

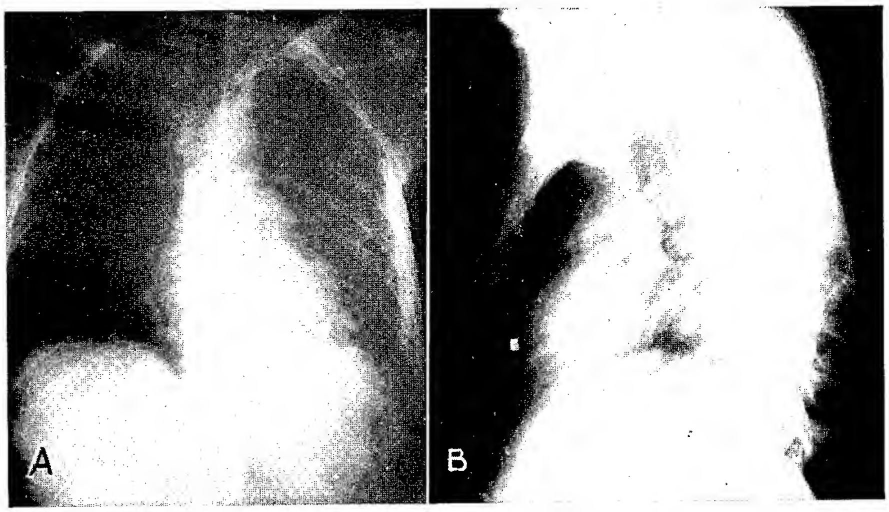

FIGURE 158 (case 2).—Preoperative roentgenograms showing retained missile in left ventricle. A. Posteroanterior roentgenogram. B. Lateral roentgenogram.

doubt that the risk of rupture of the myocardial hernia was real and that it was aggravated by the presence of the foreign body in it.

Case 3.—A third instance of damage to cardiac structures by a retained foreign body was observed by Maj. Fred J. Jarvis, MC. In this instance, the wall of the right ventricle underwent such a degree of degeneration from the presence of the underlying migratory missile that death ensued.

Other indications for surgery.—Two additional factors sometimes assumed importance in the decision to remove intracardiac foreign bodies. One was pain, the other cardiac neurosis.

Pain was associated with some of the pericardial foreign bodies in this series, but with only one of the intracardiac missiles. In this case, the object had migrated from the auricle to the ventricle. A similar case was observed by Lt. Col. (later Col.) Laurence Miscall, MC.

Cardiac neurosis sometimes became a pressing indication for surgery. In spite of every effort to reassure them, all the patients in this series with foreign bodies in or near their hearts wanted them removed. Their apprehensions bore out Grey Turner's (*1*) remark, "In addition to the characteristic cardiac symptoms * * * there may be neurotic manifestations which mainly depend on the attitude of the patient to the knowledge that he harbors a foreign body in one of the citadels of his well-being."

Size and location were other factors which influenced the decision for and against surgical intervention. Small foreign bodies left in situ were regarded as less hazardous than larger ones, and it was also thought that they were associated with less risk of myocardial damage. An additional reason for leaving them undisturbed was that they became encapsulated more readily and more firmly than larger missiles and were therefore technically more difficult

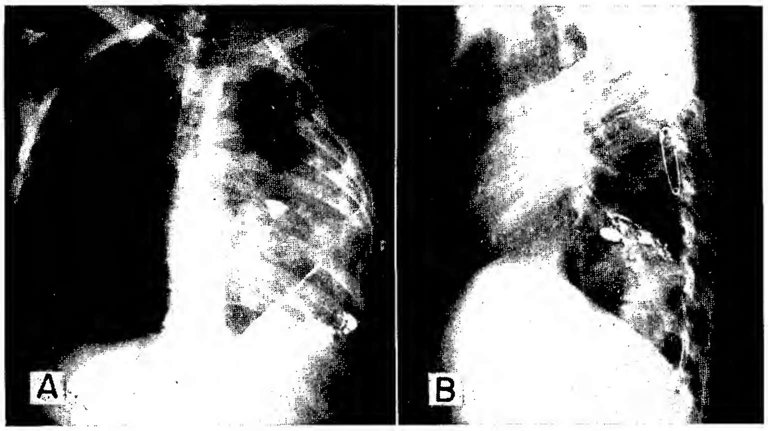

FIGURE 159 (case 4).—Preoperative roentgenograms showing retained fragment in left auricle. Radiopaque oil is seen in empyema pocket. A. Posteroanterior view. B. Lateral view.

to remove. For these reasons, small, silent foreign bodies in and near the heart were allowed to remain in situ in 15 cases at the 160th General Hospital during the period in which 13 similar fragments were removed surgically.

Combined indications.—As might have been expected, more than one indication for surgery was sometimes present, as the following case history demonstrates:

Case 4.—This soldier, following injury by a shell fragment in the left anterior aspect of the chest, developed an empyema, from which both hemolytic *Staphylococcus aureus* and *Clostridium welchii* were cultured. He had been treated by decortication followed by open drainage at the 160th General Hospital. In the 6 months after injury, he had three massive episodes of bleeding and two minor episodes. He also had bouts of pyrexia to 103° F., which did not appear to be connected with his empyema. Posteroanterior and lateral roentgenograms (fig. 159) revealed a shell fragment in the left auricle. Electrocardiographic studies before operation (fig. 160) showed right axis deviation with low R_1 and deep S_1, low diphasic T_1, and upright, pointed T_2 and T_3. The precordial leads were normal. The abnormalities suggested damage to the anterior wall of the myocardium but were not helpful in localizing the missile.

At operation (fig. 161) on 18 May 1945, the empyema was found to communicate with a laceration in the pericardium and the underlying left auricle; the auricle was adherent to the pericardium. A laceration in the auricle was plugged by a large, infected, intracardiac hematoma. The missile, which was 2 by 1 by 1 cm. and was surrounded by cloth, lay in this clot. It was readily removed from the left auricle, together with the cloth and the infected clot. *Cl. welchii* and *Escherichia coli* were grown on direct culture from the material removed.

After operation, the empyema rapidly resolved and there were no further episodes of hemorrhage or pyrexia. Serial electrocardiograms (fig. 162) showed deep and sharp inversion of T_1 and inverted T in CF_6 but no other significant change.

This case appears to embrace most of the indications for removal of an intracardiac foreign body (including an extensive thrombus), a potential embolus, gross intracardiac contamination and infection, pericardial involvement, and damage to the myocardium with repeated hemorrhages.

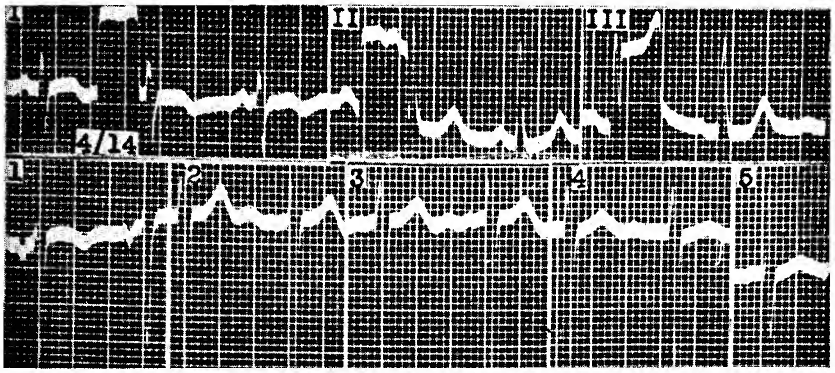

FIGURE 160 (case 4).—Electrocardiogram taken before operation showing possible damage to anterior myocardial wall. See figure 147 for key.

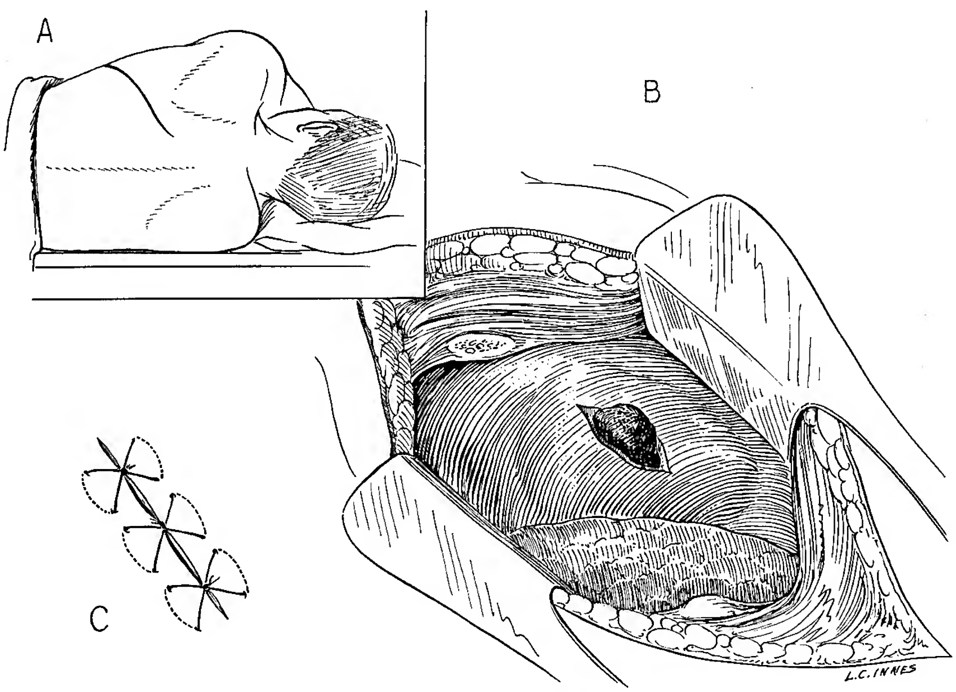

FIGURE 161 (case 4).—Technique of removal of retained shell fragment from left auricle. A. Patient in right lateral decubitus. B. Laceration of left auricle plugged by infected hematoma. C. Closure of laceration by pericardioauricular sutures.

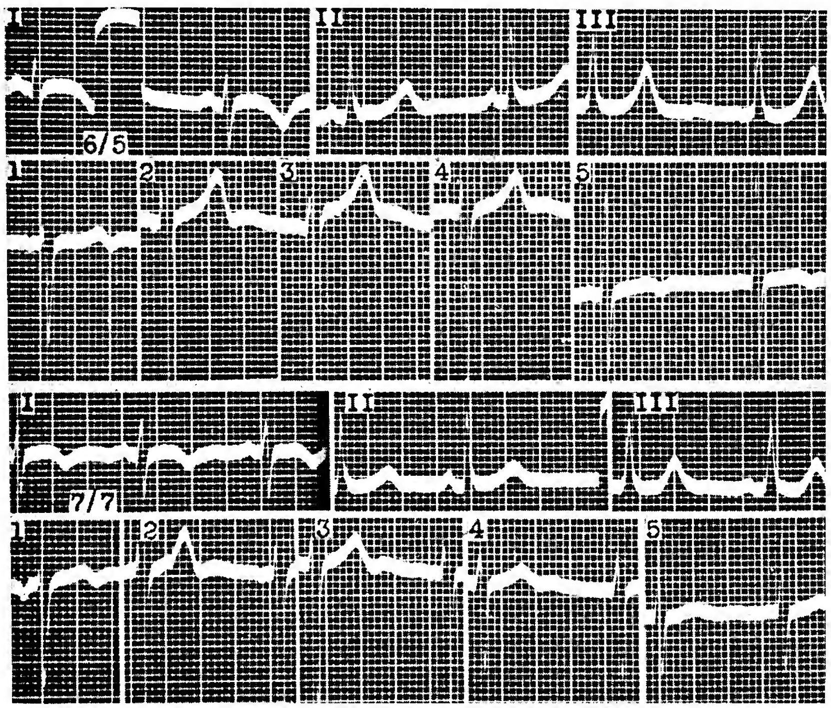

FIGURE 162 (case 4).—Electrocardiogram after left auricular cardiotomy and removal of intra-auricular shell fragment. See figure 147 for key.

Principles of Surgery

A successful attempt to remove a foreign body from the heart depended upon the observance of certain fundamental principles governing exposure of the involved area and manipulation of the heart itself. The most important of these principles were:

1. Adequate, direct exposure of the affected area. This necessitated the use of a variety of approaches (fig. 163), depending upon the special problem at hand. The pleura was opened routinely, but no standard or inflexible cardiac approach was relied upon.

2. Conservation of the skeleton of the thoracic cage. The free division of ribs, cartilage, and sternum was often necessary to reach the heart. The division of bone and cartilage did no harm, but it was essential that these structures be preserved in situ. Complete reconstruction of an intact chest wall was necessary at the end of the operation. No tissue or bone was resected, and nothing was discarded. As a result, there was neither deformity nor defect at the end of the operation.

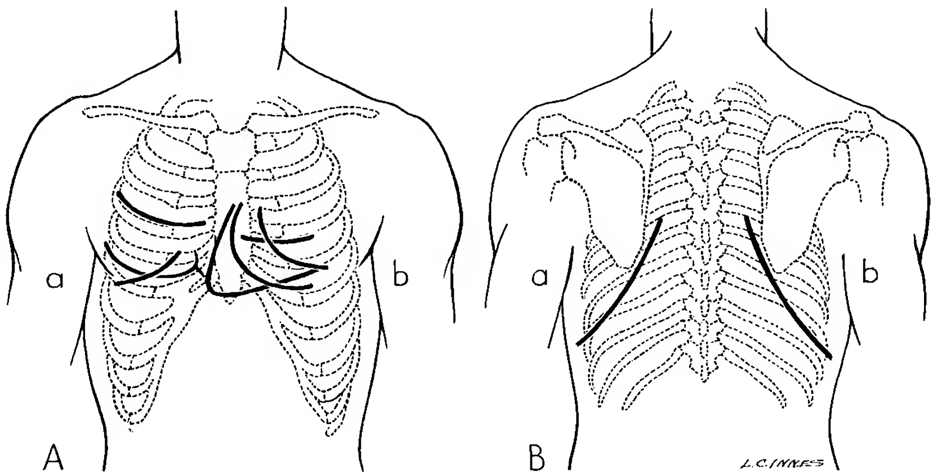

FIGURE 163.—Incisions used to obtain exposure of foreign bodies in heart. A. Anterior aspect, showing: Approach to superior vena cava and right auricle (a), and approach to anterior and lateral aspects of right and left ventricle (b). B. Posterior aspect, showing: Approach to posterior aspect of left ventricle (a), and approach to posterior aspect of right and left auricles (b).

3. Maintenance of a moist epicardium during the period of cardiac exposure. It was thought that the 1 percent procaine hydrochloride solution used to keep the epicardial tissues moist might also have the additional advantage of reducing cardiac irritability.

4. Minimal dislocation of the heart from the position of optimal function. To perform cardiac surgery with minimal cardiac dislocation often taxed the ingenuity of the surgeon, but it was essential for a successful result.

Surgical Technique

Both the approach and the procedure for the removal of foreign bodies in and about the heart depended upon their location. The various approaches described were all used successfully in one or more cases in this series. Another extracardiac approach to the heart, by way of the pulmonary veins to the left auricle or even the left ventricle, was tentatively discussed, but no occasion to use it arose.

Right ventricle.—When the object was in the right ventricle (fig. 164), the best approach was through the fifth or the fourth intercostal space (fig. 165), which exposed the left portion of the right ventricle and the left border of the left ventricle. The pectoralis major was split laterally and divided medially. The intercostal muscles were divided, and the internal mammary vessels were ligated. The cartilage superior to the incision was divided near the sternum, after which the rib-spreader was inserted. If additional exposure

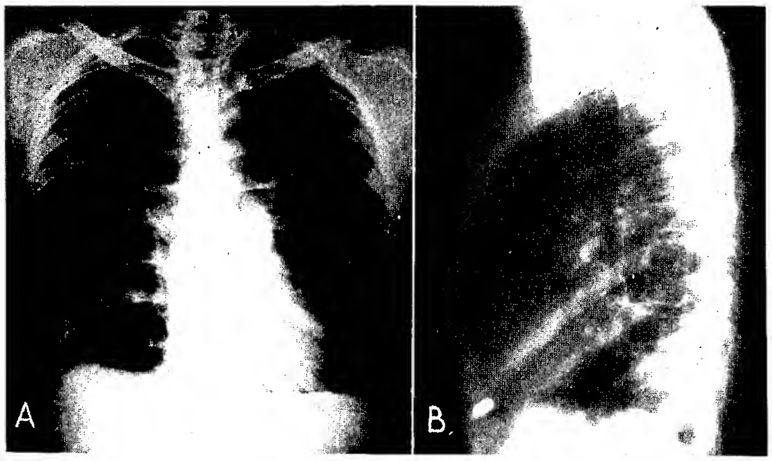

FIGURE 164.—Roentgenograms showing foreign body in chamber of right ventricle. Before these films were made, the right hemithorax had been cleared of an infected hemothorax. A. Posteroanterior view. B. Lateral view.

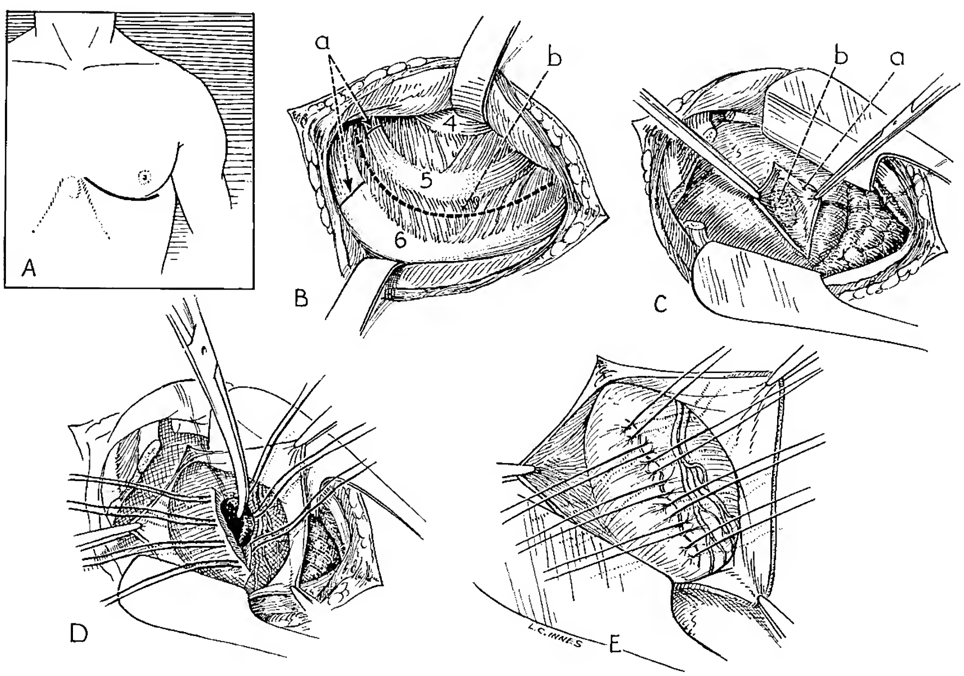

FIGURE 165.—Technique of removal of foreign body shown in figure 164. A. Skin incision over the anterior left fifth interspace with optional extension. B. Bony cage exposed: fifth and sixth cartilages divided (a), fifth intercostal space incised (b). C. Exposure of right ventricle by incising fused pericardium (a), and exposing foreign body (b). D. Placement of hemostatic sutures in right ventricular wall and removal of foreign body. E. Enlargement demonstrates crossing of hemostatic sutures.

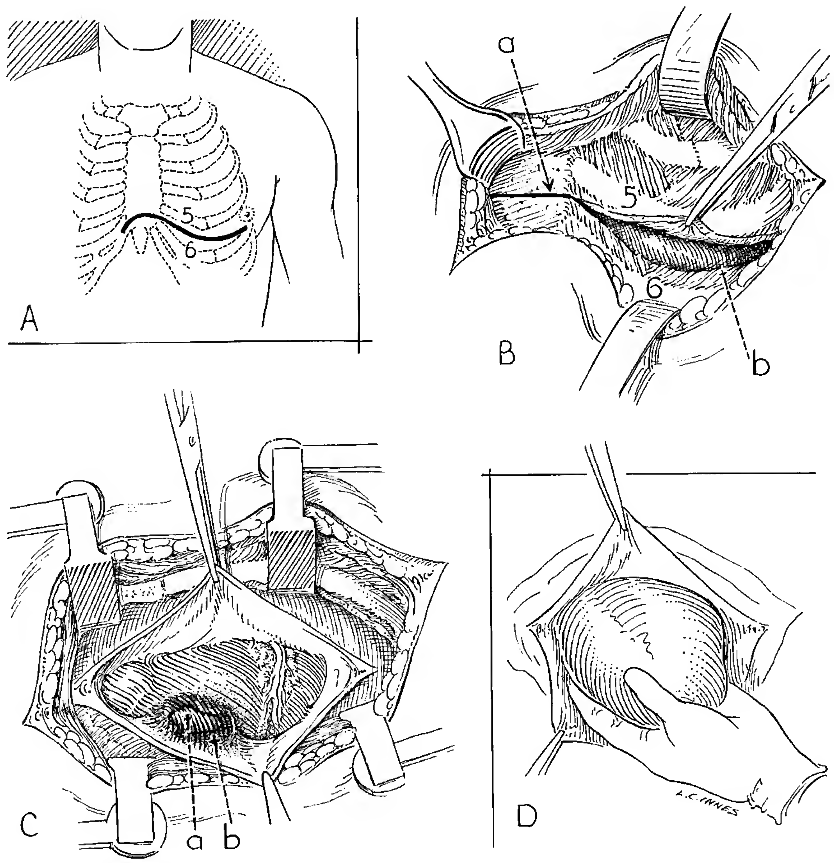

FIGURE 166.—Technique of combined intercostal-transsternal approach to right aspect of right ventricle and phrenic surface of heart and pericardium. A. Skin incision. B. Transverse section of sternum with Gigli's saw (a), incised left fifth intercostal muscle (b). C. Exposure of foreign body with aid of Tudor Edwards' double retractor: foreign body (a), localized abscess of pericardium (b). D. Digital stabilization of dislocated heart.

was necessary, it could be obtained by the optional T-incision and division of the sixth and seventh costal cartilages.

After the pericardium and pleura had been opened widely, this approach permitted palpation of a foreign body in the right ventricle. As a rule, the cardiac chamber was not opened, nor was any attempt made to remove the missile, until it had been located by palpation. When it had been located, two rows of sutures were placed immediately over the object, on either side of the projected incision. These sutures, which served as hemostatic guy or control sutures, were used by the assistant to prevent blood loss from the opened heart between intracardiac maneuvers. The second row of sutures also served as a

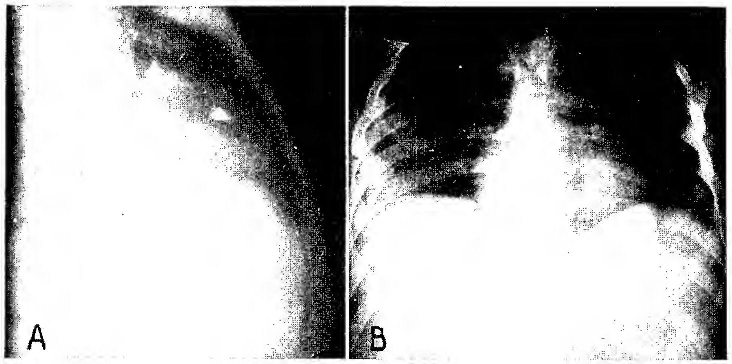

FIGURE 167.—Roentgenograms showing missile in right auricle. A. Lateral view. B. Posteroanterior view.

sort of second line of defense, in the event that any of the sutures in the first row pulled out.

After the missile had been stabilized as well as possible with the fingers, a small epicardial incision was made with the scalpel, and a pointed forceps was thrust through the myocardial wall and spread open; an opening sufficiently large to permit the insertion of a Kocher clamp was thus created. The foreign body was then grasped and extracted with this instrument. During these manipulations, the assistant crossed the control sutures and thus produced hemostasis.

Once the fragment had been removed, the inner row of control sutures was tied across the incision. The second line of sutures was then tied over a small free pericardial graft, over which a second, larger, free pericardial graft was sutured into place. Postoperative cardiac tamponade was avoided by leaving the lateral angle of the pericardial incision open into the pleural space.

Chromic catgut sutures No. 00 were used, on atraumatic noncutting needles. In retrospect, it might have been wiser to use silk for the ventricular closure.

Diaphragmatic surface of the heart.—When the foreign body lay farther to the right or was on the diaphragmatic surface of the heart, the intercostal incision described was combined with a transverse sternal section (fig. 166). Tudor Edwards' double retractor could be usefully adapted for this procedure. The sternum was readily reconstituted with wire.

When the auricle or the right side of the ventricle had to be approached, the reverse of this incision could be used by following precisely the same technique on the right side of the chest.

Right auricle.—When the missile was in the right auricle (fig. 167), a right anterior approach was usually best (fig. 168). The third, the fourth, or even the fifth interspace was used, depending upon the location of the foreign body. The third interspace, for instance, was incised, with section of the

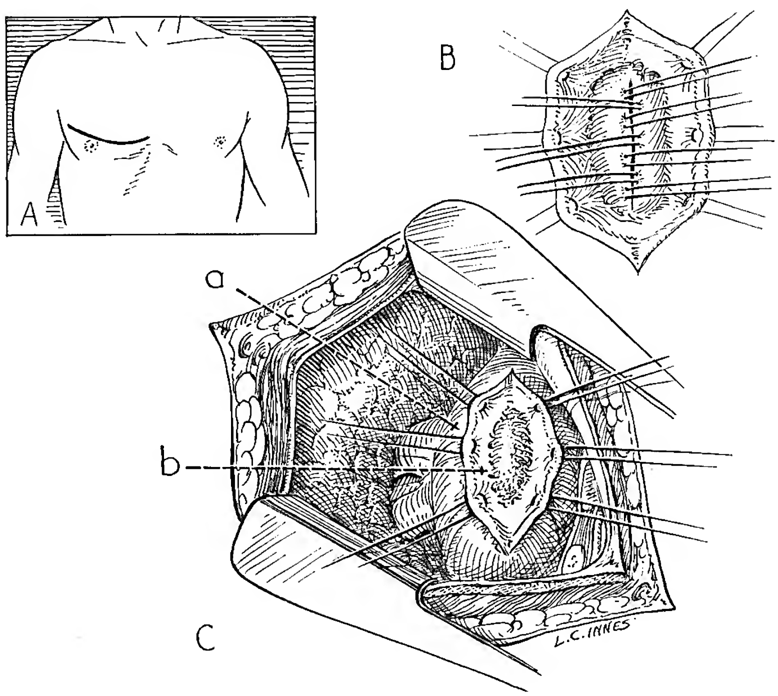

FIGURE 168.—Technique of removal of foreign body shown in figure 167. A. Incision for anterior approach to right atrium. B. Closure of incision with pericardioatrial and atrial sutures. C. Exposure of right atrium (a), reflected pericardium (b).

third and fourth costal cartilages near the sternum, to provide exposure of the upper portion of the right auricle. After the pericardium had been opened, control sutures were placed in the auricular wall by the technique described for their application in the ventricular wall. The auricular myocardium was often too thin to hold sutures. If the structures were adherent, as in the case illustrated, pericardial tissue could be included with auricular tissue in the second suture line.

Left auricle.—If the foreign body was in the left auricle, the approach shown in figure 161 was used. In this case (case 4, p. 367), the laceration of the auricle and pericardium was plugged by an infected clot, and the fusion of the two structures made the intracardiac portion of the operation perfectly simple.

Pericardium.—In this series, intrapericardial missiles were removed by a posterior approach that exposed the left auricle on either the right or the left side. This technique was not used in any intracardiac operation at the 160th General Hospital. When the patient was placed in ventral decubitus (fig. 169), the posterior incision provided adequate exposure.

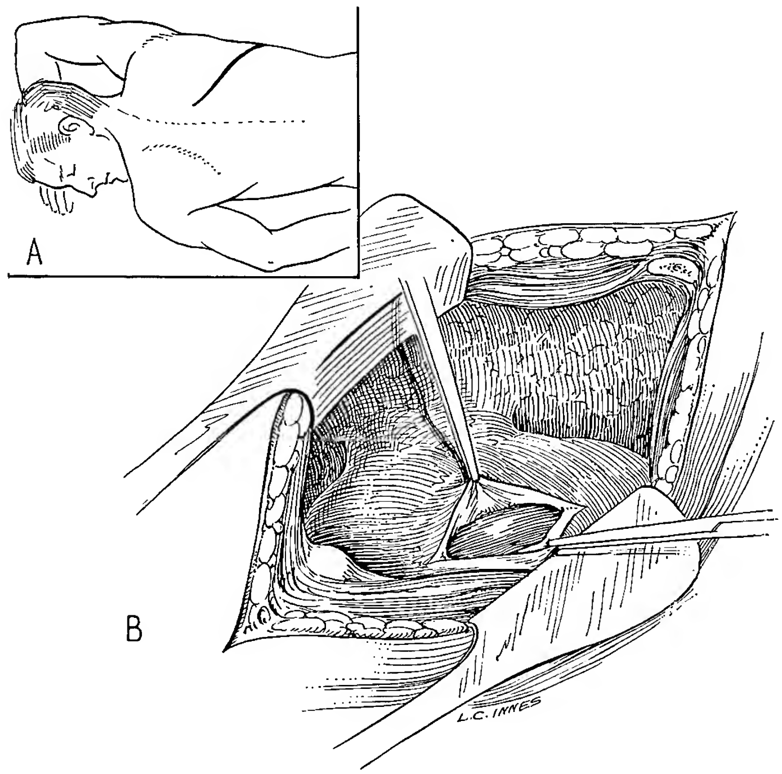

FIGURE 169.—Technique of posterior approach to pericardium and heart on right. A. Incision with patient in ventral decubitus. B. Exposure.

In one case in which this approach was used (fig. 170), an extremely thin-walled auricle was encountered in a completely free pericardial space. Bleeding from the auricular wall was so free when an attempt was made to place the hemostatic sutures that this technique had to be abandoned. An approach through the auricular appendage proved equally unsafe. An extracardiac approach was therefore devised, by exposure of the superior vena cava (fig. 171). Control tapes were placed around this vessel, an incision was made into it, and a forceps was slipped down the lumen and into the ventricle. This maneuver permitted removal of the missile without difficulties.

Behavior of the Heart During Cardiac Surgery

The electrocardiographic tracings made at operation in some cases in this series were useful in demonstrating manipulations that were not well tolerated by the heart. These manipulations included cardiac dislocations, hemostatic cardiac grips, and extensive maneuvers within the cardiac chambers.

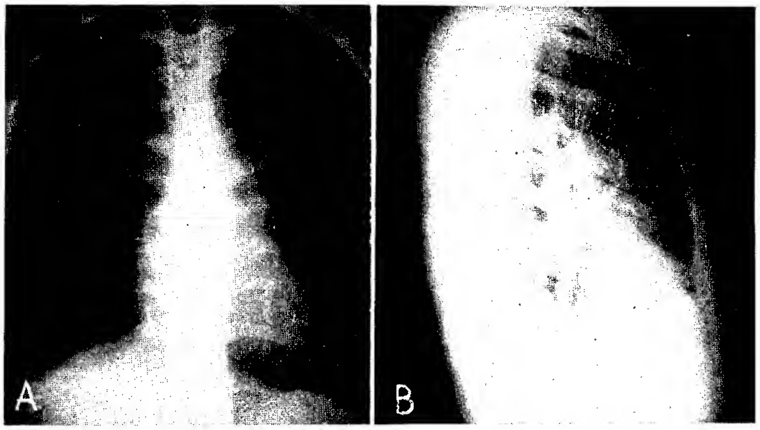

FIGURE 170.—Roentgenograms showing foreign body in interauricular septum and right auricle. The widened mediastinum was found at operation to be caused by a hematoma. A. Posteroanterior view. B. Lateral view.

Cardiac dislocation.—In some instances, dislocation of the heart at operation caused runs of ventricular extrasystoles, diminished cardiac output, and transitory bundle branch block. Whether the dislocation was accomplished manually or by means of an apical suture, it was not well tolerated, as the following case history shows:

Case 5.—At operation, this foreign body (fig. 172) was found extracardially, in a pericardial abscess well back on the diaphragmatic surface of the heart. The abscess contained about 18 cc. of pus. To gain access to this area, the heart had to be lifted out of the pericardial sac (plate II). This maneuver caused a fall in blood pressure, accompanied by circulatory failure, which made it necessary to replace the heart frequently, after relatively short periods of dislocation, to permit a return to normal conditions before the operation could be proceeded with. Many irregularities in rhythm occurred, which were apparently extrasystoles, and marked cardiac dilatation, particularly of the right ventricle, also developed, so that the heart became too large for the pericardial sac (plate III). After it was replaced, the pericardium was left partly open.

Electrocardiograph tracings taken during operation (fig. 173) showed variations in rhythm consisting of ventricular extrasystoles (at 300), wandering pacemaker, varying P–R interval, and A–V nodal rhythm. It was at the time the nodal rhythm occurred, during a period of dislocation of the heart, that a particularly prolonged and alarming episode of circulatory failure developed. After recovery, normal sinoauricular tachycardia returned (fig. 173).

An additional change in the electrocardiograms was also related to dislocation of the heart. At 2:57 o'clock (fig. 173), the S-wave became broad and notched and the QRS interval lengthened to 0.13 second, in contrast to the normal complexes at 2:07 and 2:37 before cardiac manipulations. While it is unfortunate that this abnormality was recorded only in lead II, it may be regarded as indicating at least interventricular block or incomplete bundle branch block, probably on the right side. The abnormal QRS complexes persisted throughout the operation, but 4 days later, observations were normal. At operation,

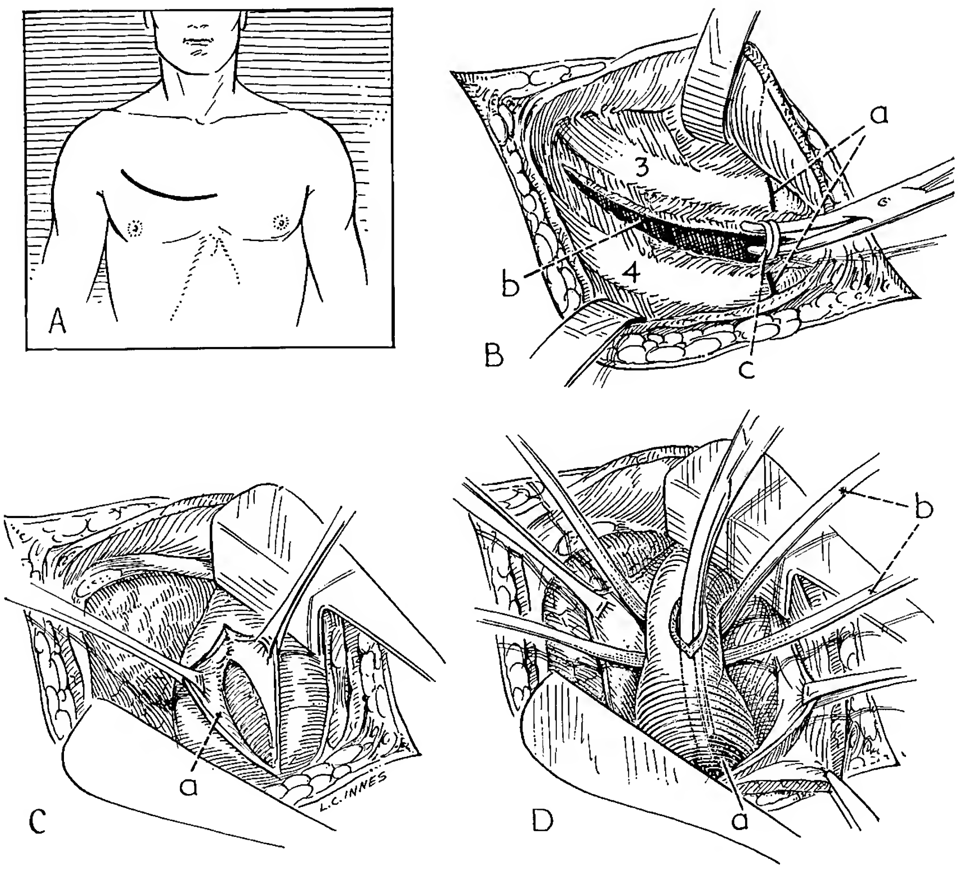

FIGURE 171.—Technique of removal of foreign body in right auricle by incision in superior vena cava shown in figure 170. A. Anterior skin incision. B. Third intercostal space incision (a), section of third and fourth costal cartilages close to sternum (b), and exposure of intercostal vessels to permit their division (c). C. Excellent exposure of superior vena cava by this approach: pericardium incised (a). D. Incision into vessel and removal of right auricular foreign body (a), tapes placed around superior vena cava to control hemorrhage (b). This technique was used in this case because the pericardial space was free and the auricular wall too thin to hold guy sutures.

the delay in conduction could be correlated, by direct visual inspection, with dilatation of the right ventricle. This extremely unusual observation in a human subject was considered to be caused, at least in part, by the increased time necessary for conduction of the impulse through the greatly dilated right ventricle.

The intolerance of the heart to dislocation was demonstrated in this case in two ways, (1) by ventricular dilatation with incomplete bundle branch block, and (2) by varying types of arrhythmia and circulatory collapse. Obviously, dislocation of the heart may produce torsion of the great vessels and obstruction to outflow of blood, with (1) a fall in blood pressure resulting from the diminished cardiac output and (2) ventricular dilatation resulting from the increased resistance to blood flow.

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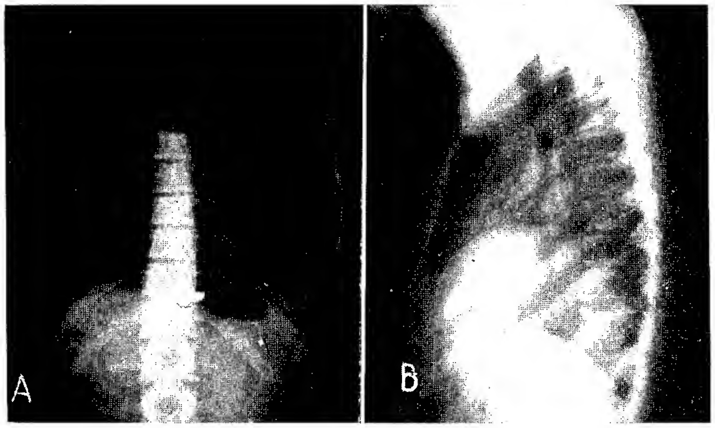

FIGURE 172 (case 5).—Roentgenograms showing foreign body in pericardial abscess well back on diaphragmatic surface of heart. A. Posteroanterior view. B. Lateral view.

This sort of experience led surgeons on the thoracic surgery service at the 160th General Hospital to avoid the apical suture as a means of exposing inaccessible areas of the heart. The situation encountered in combat-incurred wounds is quite different from the circumstances of civilian surgery, in which a planned approach permits precise and comfortable exposure of any part of the heart.

Obstruction of the cardiac blood flow.—Experience showed that the classical hemostatic cardiac grips intended to provide a bloodless surgical field were also poorly tolerated. These maneuvers disturbed cardiovascular dynamics and were therefore used only as a last resort.

The intolerance of the heart to obstruction of the blood flow was in striking contrast to its stability during other cardiac procedures and certain intracardiac procedures. The surface of the heart could be manipulated, sutures taken into the muscle, and incisions made into the cardiac chambers with little evidence of disturbance.

Intracardiac manipulations.—More extensive manipulations inside the cardiac chambers by the exploring finger or by a forceps inserted to remove an intracardiac thrombus or a foreign body were less well tolerated. Sometimes no abnormalities were noted, but marked cardiac irregularity, in the form of multiple ventricular extrasystoles, were common. The case, already described (case 1, p. 357), in which three cardiotomies were necessary, demonstrates this point particularly well. As the foreign body was grasped and extracted from the right ventricle, electrocardiographic tracing (fig. 153) showed showers of ventricular extrasystoles from different foci in both ventricles; runs of ventricular tachycardia lasted as long as 16 seconds. Direct observation of the irregular heart action and examination of the electrocardiogram raised the

FIGURE 173 (case 5).—Electrocardiograms taken during operation for removal of pericardial foreign body. See figure 147 for key. The number in the lower corner of each segment indicates the clock reading at which the tracing was made. Note the nodal rhythm, which occurred during a prolonged and alarming episode of circulatory failure while the heart was dislocated (plate II).

fear of impending ventricular fibrillation, but at the end of the operation, when the irritating forceps and the missile had been removed from the ventricular chamber, the tachycardia ended promptly and the P–R interval returned to normal in three beats. All of these irregularities were relatively benign.

Other causes of cardiac irritability.—Minor evidences of cardiac irritability were observed at operation, such as extrasystoles and wandering pacemaker, varying P–R interval, and even A–V nodal rhythm, but these phenomena were not usually accompanied by any significant clinical manifestations. These minor abnormalities were often evoked by procedures not related to the heart, such as endotracheal intubation, spreading of the ribs, and manipulations of the hilar and mediastinal structures. It was thought that keeping the surface of the heart moist with warm physiologic salt solution or procaine hydrochloride solution was important in reducing the tendency toward irritability.

Postoperative Management

The postoperative care of a patient who had undergone cardiac surgery was essentially the same as the care of a patient who had undergone any serious chest surgery. Patients who had required ventricular cardiotomy were kept in bed for 3 weeks, even though the electrocardiographic tracings had usually returned to normal within a few hours after operation.

FOREIGN BODIES IN AND ABOUT THE GREAT VESSELS

Indications for Surgery

The danger of erosion and suppuration as the result of the retention of large missiles in close proximity to thoracic blood vessels was quite real. At least three deaths are known to have occurred at other installations in the European theater as the result of erosion from this cause. In the 78 successful operations for removal of such missiles at the 160th General Hospital thoracic surgery center, there was no instance of erosion. On the other hand, abscess formation occurred in about 15 percent of the cases; clothing, bone fragments, and other foreign material entered the body with the shell fragment in 30 percent of the cases; and pathogenic bacteria were found on 67 percent of the material that was cultured on removal.

On the basis of these facts, it became established policy at this chest center to remove all foreign bodies in the mediastinum adjacent to the great vessels if they measured 1 cm. or more in two dimensions. The decision to remove smaller objects or permit them to remain in situ was made on the indications in each case.

Removal of the foreign bodies seldom presented any technical difficulties. At the 160th General Hospital, operation was unsuccessful in only one case, the third undertaken. The fact that there were no deaths in the 78 cases in which the objects were removed seems to support the contention that their removal was safer than their continued retention.

The only cases in this series which warrant special discussion are the three instances of migratory intravascular objects, which will be described in some detail.

MIGRATORY INTRAVASCULAR FOREIGN BODIES

In 1942, Straus (*2*) collected from the world medical literature 32 instances of migratory intravascular foreign bodies and added to the collection a case which he had himself observed. A second review of the same literature in 1945 brought to light nine additional cases that Straus did not include in his material. Undoubtedly, other cases were overlooked in both reviews, while still other cases have not been reported at all.

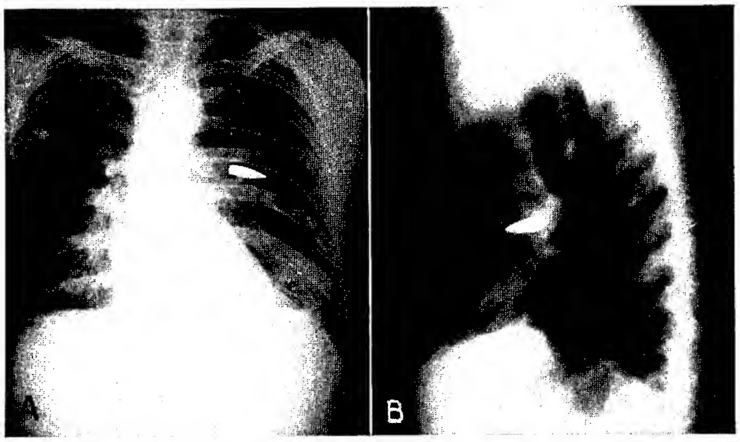

FIGURE 174 (case 6).—Roentgenograms showing .30-caliber bullet in hilar region of left lung. The bullet was later found to be within one of the radicles of the left pulmonary artery. A. Posteroanterior view. B. Lateral view.

Almost without exception, the migratory foreign bodies in these 42 cases were bullets or shell fragments, the majority of which originated in combat-incurred injuries.

The infrequency of such cases, the bizarre courses of many of the embolic missiles, and the dramatic developments often associated with their migration warrant a presentation of the three such cases encountered at the 160th General Hospital thoracic surgery center, together with a brief comment on certain of their features.

Case 6.—A 30-year-old soldier was wounded in the left infraclavicular region by a .30-caliber machinegun bullet while in combat in Belgium on 26 December 1944. The wound was debrided and sutured the same day at a forward installation. Roentgenograms of the chest taken at this time revealed that the bullet was located posterior to the hilus of the left lung.

When the patient was evacuated to the 128th General Hospital, Bishopstrow, England, it was decided that the size of the missile and its proximity to the hilus of the lung constituted valid indications for its surgical removal. He was therefore transferred to the chest center at the 160th General Hospital on 8 January 1945.

Initial roentgenograms (fig. 174) confirmed the previous findings. Routine fluoroscopic studies for precise localization of the missile suggested nothing more remarkable than the presence of a pulsating bullet intimately associated with the left hilar structures. There seemed no doubt that it could readily be removed through a conventional posterolateral approach.

Thoracotomy was accordingly performed through this approach on 19 January 1945. After resection of 12 cm. of the seventh rib, the bullet could be palpated in the central portion of the left upper lobe. Its location was confirmed by palpation by the first assistant. When, however, the surgeon palpated the area for a second time, he was chagrined to find that the missile had vanished. A thorough search of the entire left lung, including the hilus, and of the posterior mediastinum and the pericardium failed to locate the bullet, and it was suspected that it had fallen into the tracheobronchial tree. When this possibility

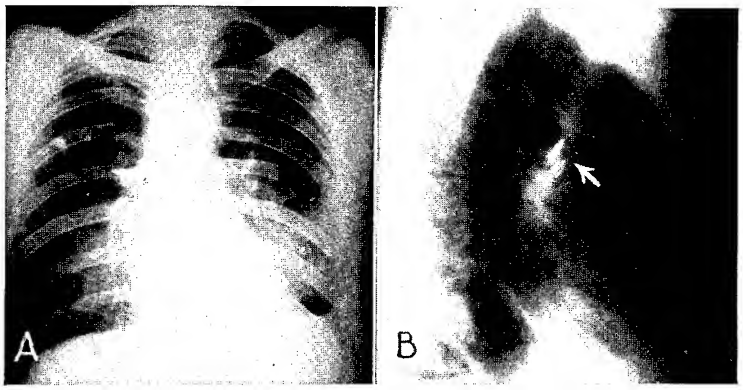

FIGURE 175 (case 6).—Roentgenograms taken immediately after left thoracotomy. The bullet now seems to be in the hilus of the left lung. The double image of the bullet in the lateral view is explained by its pulsation with the pulsation of the pulmonary artery. A. Posteroanterior view. B. Lateral view.

was excluded by immediate bronchoscopy, no further manipulations were attempted, and the chest was closed.

Recovery was completely uneventful and the patient was allowed out of bed daily after the first 24 hours. Roentgenograms taken immediately after operation (fig. 175) showed that the bullet that had previously been seen in the hilar region of the left lung (fig. 174) was now lying horizontally, just to the right of the body of the sixth dorsal vertebra, pointing outward. The pulsations indicated that it was in contact with the area of the pulmonary artery. It was concluded that the missile was definitely in the right pulmonary artery.

A second thoracotomy was performed on 20 February 1945, through the third intercostal space anteriorly (fig. 176). The third and fourth costal cartilages were divided close to the sternum. There was no evidence of altered blood flow in the lungs. The bullet was palpated in the hilus of the right lung at and in the mediastinum, posterior to the superior vena cava.

The right pulmonary artery was isolated, and a tape was placed about it proximal to the foreign body. The missile, point outward, was digitally manipulated away from the hilus into the pulmonary artery of the upper lobe, the milking process being continued until its point presented beneath the visceral pleura in the interlobar fissure. Here, the pleura was nicked, and the presenting tip was thrust upward through the opening and grasped with a Kocher clamp. The missile was then delivered in toto by slowly stretching the terminal branches of the pulmonary arterial tree. Hemorrhage was controlled by circumferential mattress sutures of catgut in the lung at the point of removal of the missile. The wound was closed without drainage.

The patient was up and about after the first postoperative day. His recovery was completely uneventful, and he was returned to the Zone of Interior for rehabilitation on 30 March 1945.

Case 7.—This soldier was wounded on 14 October 1944, in action in France, by a shell fragment that entered through the upper part of the right posterior axillary line. The wound of entrance was debrided and closed the same day at the 60th Field Hospital. Aspiration of a right hemothorax yielded 500 cc. of blood. Roentgenograms of the chest (fig. 177) revealed a foreign body in the right upper mediastinum, 3 cm. posterior to the right sternoclavicular joint.

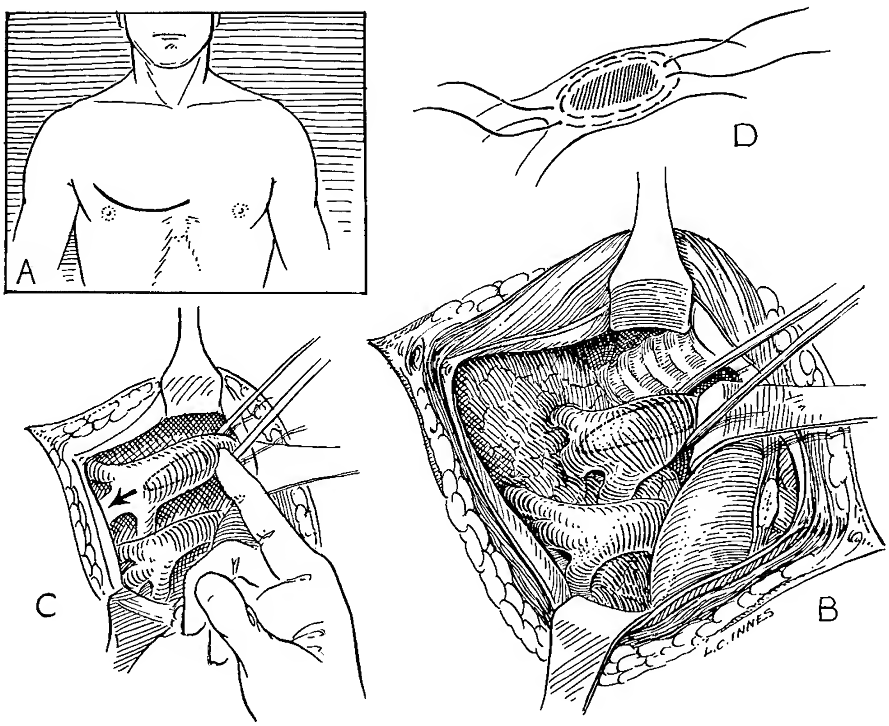

FIGURE 176 (case 6).—Technique of removal from right pulmonary artery of foreign body shown in figures 174 and 175. A. Skin incision. B. Exposure of right pulmonary artery. Umbilical tape placed proximally around the main pulmonary prevents escape of the bullet to opposite pulmonary artery or right ventricle. C. Milking of bullet to periphery of lung, into one of the smaller radicles of the pulmonary artery. D. Opposing hemostatic sutures at site of removal of bullet.

After the patient reached the 154th General Hospital, Wroughton, England, a pericardial friction rub was heard. On 21 October, a bruit was discovered over the right supraclavicular fossa, and it was noted that both the brachial and the radial pulses were absent in the right arm. Thoracentesis, repeated on 7 November, yielded what was at first thought to be fresh blood. It was later found to be old, changed blood of the so-called grapejuice type.

In view of the roentgenologic and clinical findings, the patient was transferred to the thoracic surgery center at the 160th General Hospital on 10 November 1944. There, it was noted that the right hand was cooler than the left and was waxy-yellow. The blood pressure in the right arm was 102/80 and in the left 122/68 mm. Hg. Fluoroscopic and roentgenologic examination led to the conclusion that the foreign body lay in close proximity to the innominate artery.

Surgical removal of the fragment was considered advisable because of (1) its size; (2) its proximity to the large vessels in this region; (3) the evident vascular damage it had caused, as attested by the bruit and the differences between the blood pressures in the right and left arms; and (4) the possibility that fresh bleeding had occurred into the right pleural cavity. The latter consideration suggested that surgical intervention be instituted promptly.

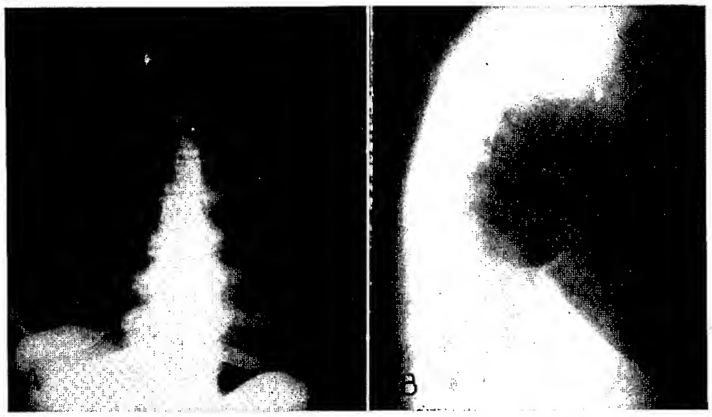

FIGURE 177 (case 7).—Roentgenograms showing retained shell fragment posterior to right sternoclavicular joint in region of innominate artery. A. Posteroanterior view. B. Lateral view.

Operation was performed on 12 November 1944 under endotracheal gas-oxygen-ether anesthesia. A U-shaped incision was made over the right upper anterior chest (fig. 178). The sternum was exposed. The internal mammary vessels were divided and ligated in the second intercostal space. The right pleural cavity was opened widely. The deep surface of the sternum was cleared of underlying structures, and the bone was split with a power saw longitudinally in the midline, from the suprasternal notch down to the level of, and out through, the second intercostal space. When the segment of sternum, with the clavicle and the first two ribs attached, was reflected upward and outward, excellent exposure of the superior mediastinum and the base of the neck was secured.

The superior vena cava and the innominate veins were retracted with tapes. The innominate artery was isolated at its point of origin from the aorta, and a tape was placed about it for hemostatic purposes. It was then dissected free up to its bifurcation into the carotid and subclavian arteries. Tapes were placed about each of these vessels. It was not possible to palpate the foreign body within the upper portion of the innominate artery, the wall of which was intact and free from scars. The artery was incised longitudinally, and the foreign body was removed. The portion of intima which had been in contact with it showed evidences of patchy destruction. After thrombi had been removed from the lumen of the vessel, bleeding was free, both proximally and distally.

The incision in the artery was closed in two layers, with interrupted No. 000 silk sutures. The first layer included the entire wall. The second sutures were introduced through the adventitia and media; a bite was taken on either side of the incision as each suture was placed, but the sutures did not pass through the lips. Fibrin foam was laid over the incision and held in place with the second layer of sutures.

The sternum was approximated with three interrupted wire sutures placed in drilled holes that had been so staggered that the medial holes were lower than the lateral holes. When the sutures were pulled tight, the sternal fragment was therefore drawn downward and inward, and a precise and stable reconstruction of the pectoral girdle was thus obtained. Great care was taken to accomplish this result because stability had been found to be of great importance after section of the sternum; the movement of loosely approximated sternal fragments was painful and could produce shock.

The pectoral muscles were approximated with interrupted sutures of No. 00 chromic catgut. The superficial fascia was similarly closed, and the skin was sutured with No. 0 black silk. No drains were used.

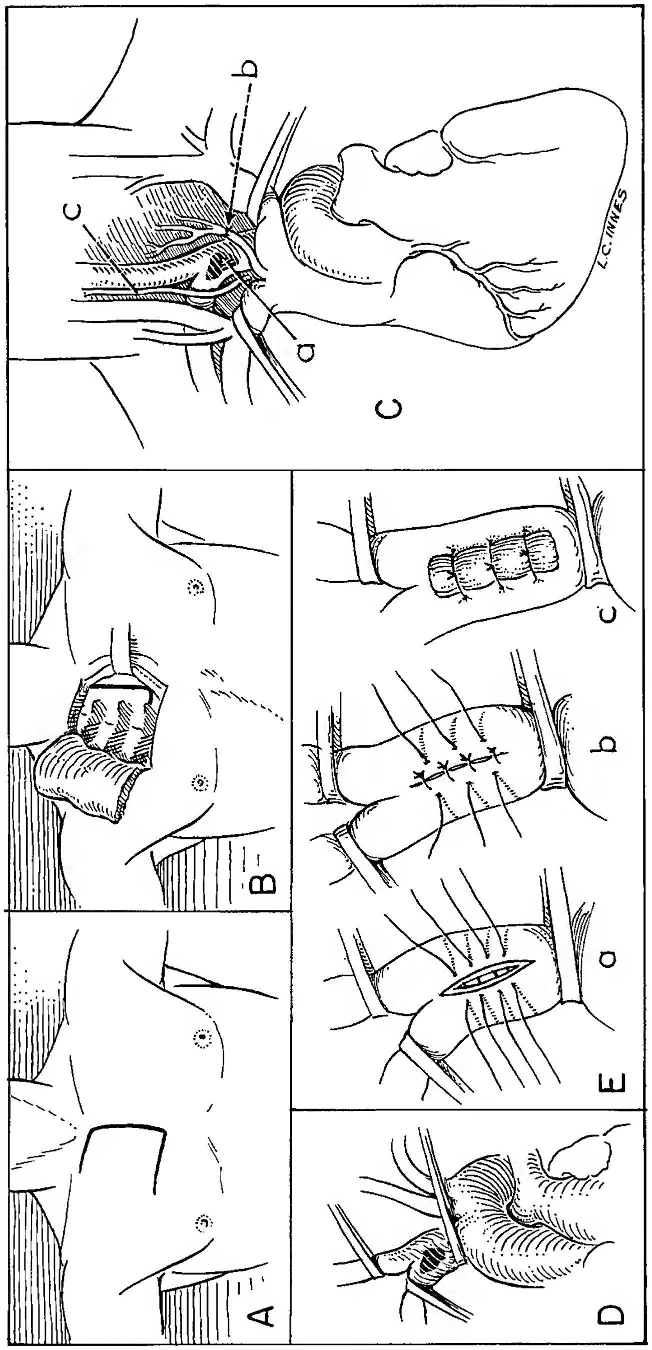

FIGURE 178 (case 7).—Technique of removal of retained missile from innominate artery. A. Incision. B. Sternal-splitting approach. C. Detail of position of foreign body in innominate artery (a), ligated thyroid vein (b), and right vagus nerve (c). D. Detail of hemostasis before removal of missile and repair of artery. E. Detail of technique of vascular closure is shown in (a) and (b), fibrin foam used to reinforce vascular closure represented by (c).

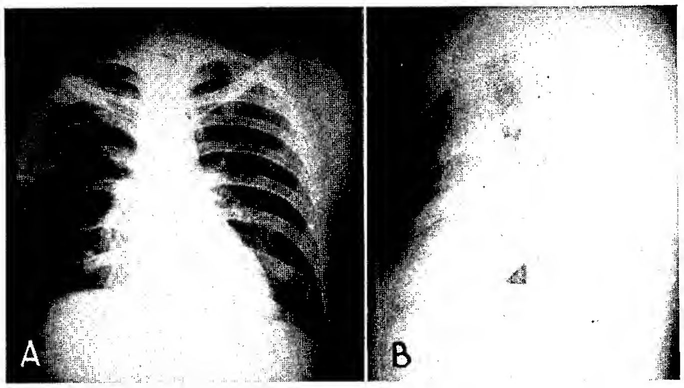

FIGURE 179 (case 8).—Roentgenograms 3 days after wounding showing clear lung fields. A. Posteroanterior view. B. Lateral view.

Immediately after operation, the pulse in the right arm was barely perceptible. The first postoperative day, the blood pressure was 122/80 mm. Hg in the left arm but remained unobtainable in the right arm. The second postoperative day, the right stellate ganglion was infiltrated with procaine hydrochloride. The right arm immediately became warm, and a systolic blood pressure of 68 mm. Hg could be obtained. On 17 November, the blood pressure was 132/60 mm. Hg in the left arm and 98/76 in the right arm. On November 25, the respective pressures were 124/86 and 108/64 mm. Hg. On 15 January 1945, the blood pressures were the same in both arms.

The patient was heparinized for 3 days after operation. The clotting time usually averaged from 9 to 15 minutes but on a single occasion was 45 minutes. The hemothorax still present after operation was evacuated by aspiration and required no further treatment. Hoarseness, the result of manipulation of the right recurrent laryngeal nerve, was present for 4 weeks after operation; then it disappeared completely. Union of the sternum was firm. When the patient was returned to the Zone of Interior on 1 March 1945 for rehabilitation, he was in excellent condition and had no evidence of any circulatory disturbance.

Case 8.—A 22-year-old soldier was struck by a machinegun bullet on 15 July 1944, while in action in France. The point of entrance was in the right axilla, at the level of the fifth rib. When he was evacuated to the 159th General Hospital, Yeovil, England, on 17 July, routine roentgenograms showed no abnormalities (fig. 179), and the lateral film established the absence of metallic objects in the retrocardiac zone.

The patient was symptom-free when he was sent to the rehabilitation barracks, and for about 3 weeks he participated in a vigorous athletic program, with no difficulties. Then, early in the morning of 13 August, he was wakened by agonizing pain in the lower left chest, accompanied by dyspnea, orthopnea, cough, and hemoptysis. Rales and diminished breath sounds were heard over the left axilla. On 15 August, roentgenograms of the chest (fig. 180) revealed a .30-caliber bullet in the hilus of the left lung. On 19 August, bronchoscopy revealed edema of the left main bronchus with an injected bleeding point on the posterolateral wall. The continued hemoptysis and the bronchoscopic findings suggested that the bullet had eroded from the pulmonary artery into the left main or descending bronchus. The patient was therefore transferred to the chest unit at the 160th General Hospital on 22 August.

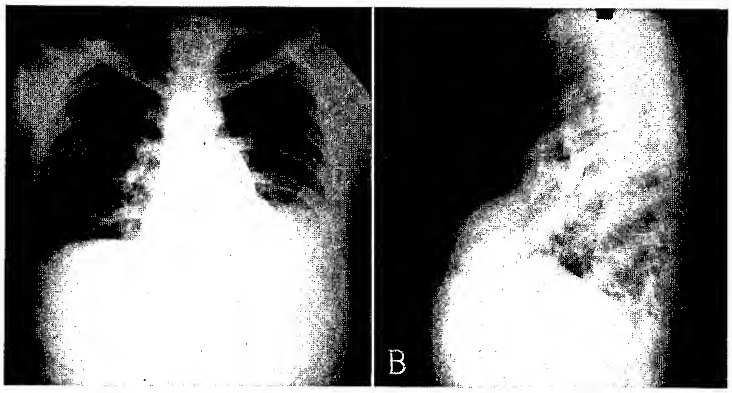

FIGURE 180 (case 8).—Roentgenograms 1 month later, 2 days after sudden onset of pain in left lower hemithorax. A .30-caliber bullet is now visualized in the hilar region of the left lung. At operation, it was found in the left inferior branch of the pulmonary artery. A. Posteroanterior view. B. Lateral view.

Since the possibility of erosion of the bullet from the pulmonary artery into the bronchus seemed an urgent indication for surgical intervention, operation was undertaken on 28 August 1944. Thoracotomy was performed through a posterolateral approach, with resection of a 16-cm. segment of the left seventh rib. Exploration revealed discoloration of the lingular portion of the left upper lobe and, to a lesser degree, of the anterior basic segment of the left lower lobe. The missile could be palpated through the interlobar fissure in the lower lobe and hilus; it seemed intimately associated with the artery. A fluctuant area, about 1 cm. in diameter, was noted over the base of the bullet.

The hilus was exposed, so that the pulmonary artery could be compressed by grasping the hilar structures from above downward between the index and middle fingers of the left hand. The digital compression not only was hemostatic but also served to stabilize the missile. With the situation thus under control, the fluctuant area was incised. The butt of the bullet was found lying in an abscess cavity anterior to, and including the anterior surface of, the lower branch of the left pulmonary artery. The body and point of the missile, however, lay within the arterial lumen, and as soon as the bullet had been extracted, the full arterial stream issued from the defect. The hemorrhage was at all times completely under control, as could be proved by voluntary release of the artery and immediate cessation of the bleeding when compression was resumed.

The abscess cavity was thoroughly debrided, and mattress sutures were placed through its wall and through the subjacent artery. Fibrin foam impregnated with penicillin was placed over the mattress sutures used to close the arterial incision before they were tied. An excellent closure of the vessel was thus effected. The gangrenous lingular portion of the left upper lobe was then resected, and the line of resection was closed with mattress sutures of No. 00 chromic catgut. The anterior basic segment of the left lower lobe, although somewhat discolored, was considered viable and was not disturbed. The lung reexpanded readily. Before the chest was closed, 100,000 units of penicillin in 50 cc. of 2.4-percent sodium citrate solution were instilled into the pleural cavity.

The left hemothorax present after operation was aspirated and did not recur. The patient was up and about the ward within 48 hours, and he was in excellent condition when he was transferred to a rehabilitation center on 1 December 1944.

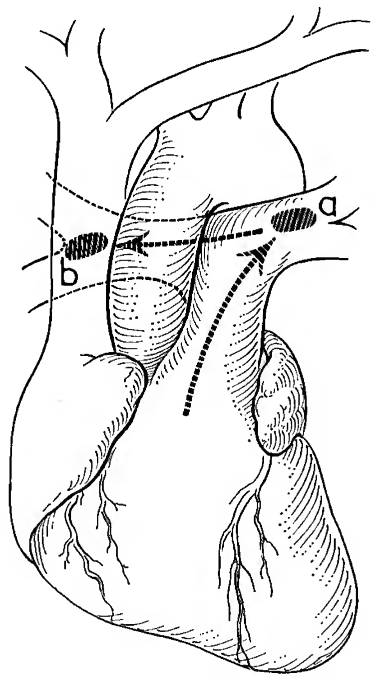

FIGURE 181 (case 6).—Migration of bullet from left pulmonary artery into main pulmonary artery and thence into right pulmonary artery: Original position of bullet in left pulmonary artery (a), and final position of bullet after migration into right pulmonary artery (b).

Migration and Clinical Consequences

Pattern of migration.—In the 42 cases of migratory intravascular foreign bodies reported in the literature up to 1945 (p. 380), migration was about equally divided between arterial and venous channels, depending upon which the object happened to enter at the time of wounding.

Apparently, there is considerable latitude in the possible patterns of migration when a foreign object enters the circulation.

In 11 of the 42 recorded cases, the missile entered one of the larger arteries and passed peripherally as an embolus. In five instances, it entered the left ventricle and was swept out into the aorta, to lodge within this vessel or within one of its branches. In one case, it passed through the left ventricle, to become embolic to the right femoral artery. Two missiles entered the ascending aorta and passed downward against the arterial stream; one came to rest in the sinus of Valsalva and the other in the left ventricle. One missile entered the pulmonary artery, migrated downward into the right ventricle, and killed the patient 7 days later, when it became embolic to the right pulmonary artery (*3*).

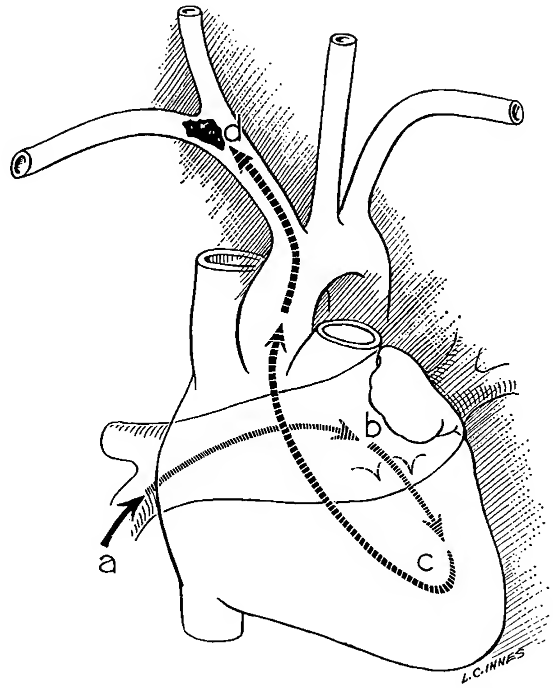

FIGURE 182 (case 7).—Probable course of migratory missile from left auricle through left ventricle and aorta into innominate artery: Foreign body enters right pulmonary vein (a), left atrium (b), left ventricle (c), and innominate artery (d).

In two instances, the missile entered one of the pulmonary veins and passed into the left ventricle.

The patterns of arterial migration described in two of the three cases of migratory foreign bodies observed at the chest center at the 160th General Hospital do not seem to have been reported previously. In one case (case 6, fig. 181) migration was from the left pulmonary artery into the main pulmonary artery and thence to the right pulmonary artery. The bullet was evidently in the lumen of the left pulmonary artery at the first operation and was dislodged by the exploratory palpation.

In one case (case 7, fig. 182), since the wall of the innominate artery and the adjacent portion of the aorta were found at operation to be intact everywhere, the course of the missile, it seems, must necessarily have been through the right side of the chest and into the pulmonary vein or the left side of the heart. The fragment was then carried as an embolus by the bloodstream into the aorta and thence to the innominate artery, where it lodged. The pericardial friction rub noted before operation suggested that the pericardium had been traversed and that the foreign body had entered the left side of the heart,

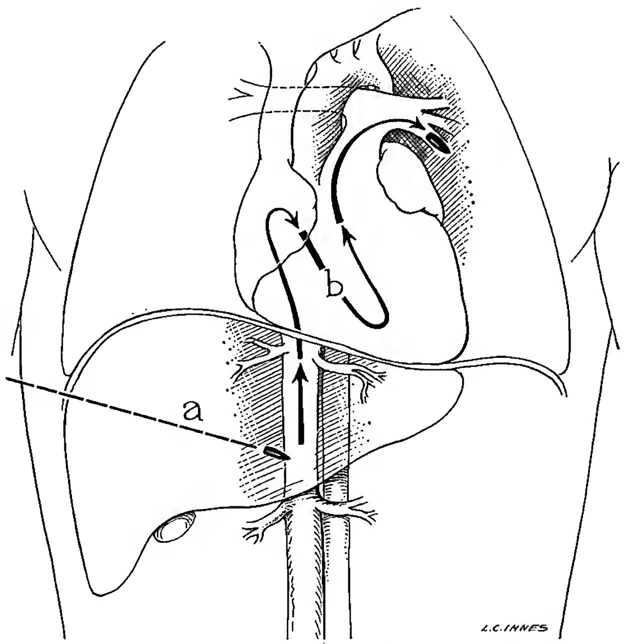

FIGURE 183 (case 8).—Course of migratory bullet from entry into inferior vena cava through right auricle and ventricle and out into left pulmonary artery: Apparent mechanism of entry into venous circuit (a) and course as embolus (b).

whence it passed into the arterial circulation. The case thus represents a penetrating wound of the heart or pulmonary artery with arterial embolism of the foreign body to the innominate artery.

In one case (case 8, fig. 183), the exact portal of entry of the bullet into the circulation can only be surmised. Since, however, the wound of entry was in the lower axilla and the chest was clear in the films taken immediately after wounding, it seems reasonable to assume that the bullet was originally in the liver. It probably began its migration in the inferior vena cava, whence it was carried to the right auricle, then to the left ventricle, and then into the pulmonary artery. It entered the left branch of the pulmonary artery and lodged in the branch to the lower lobe and lingula in such a way as to occlude the arterial supply to the lingula as it arose from the artery of the lower lobe in this region. Occlusion of the pulmonary circuit was associated with parenchymal changes.

No instances of intravenous migration of foreign bodies were observed at the 160th General Hospital thoracic surgery center during the war. In 9 of the 42 cases recorded in the literature, the object entered one of the larger veins, migrated to the right auricle, and came to rest in the right ventricle.

In three instances, it followed the same course as far as the right auricle, then traveled down the vena cava before coming to rest in one of its tributaries. In two instances, it entered one of the pulmonary veins and passed into the left ventricle. In other cases, the bullet entered the inferior vena cava and migrated to the junction of the common iliac veins; entered the right ventricle and passed into the pulmonary artery; entered the long dural sinus and then migrated into the sigmoid sinus; and entered the venous circulation through a wound in the thigh and was found at autopsy in the left ventricle. In the latter case, there was a widely patent foramen ovale. In the case reported by Straus (*2*), the bullet entered the right common iliac vein and traveled to the left pulmonary artery. Death occurred 4 days later but was not caused by the embolic missile.

In one case, a patient who harbored a missile that had migrated into the right ventricle complained of pain over the heart. With this single exception, foreign bodies migrating within the veins caused no symptoms in the recorded cases.

When a missile is in the arterial circulation, clinical manifestations vary according to the portion of the arterial tree involved. The embolic character of the object is supported by the changing symptomatology as well as by roentgenologic studies and by the findings at operation.

Varying degrees of arterial insufficiency have been reported as the result of missiles embolic in the arteries. In the case reported by Paltauf (*3*) and already mentioned (p. 388), death occurred when the migratory object became embolic in the right pulmonary artery. In a case reported by O'Neill (*4*), gangrene of the left lower extremity developed after a shell fragment became embolic from the left ventricle to the left common iliac artery; the patient survived 5 days. In one of the cases observed at the 160th General Hospital, the patient experienced severe pain when, presumably, the missile moved from the venous to the arterial circulation, and lodgment of the bullet in the branch of the pulmonary artery supplying the left lower lobe resulted in gangrene of the lingular portion of the lung on that side.

Infection.—Infection is a theoretical possibility in all cases of migratory foreign bodies. Lyle (*5*) seems to have been the first to call attention to this fact. In his case, the foreign body, which was found at autopsy in the right ventricle, had fragments of clothing adherent to it. A fibrinopurulent pericarditis was present, and gas bubbles were noted in the myocardium, but the wound of entrance in the thigh showed no evidence of infection at any time.

Diagnosis.—The possibility of intravascular migration of missiles, as the cases observed at the 160th General Hospital indicate, should be borne in mind in all instances of penetrating wounds, and the surgeon should make every effort to locate a missile whose position is not immediately obvious. If a patient who harbors a foreign body develops sudden and unexplained symptoms, as in one of these cases (case 8, p. 386), fluoroscopic and roentgenologic examinations

should be resorted to immediately, to determine whether migration of the missile is responsible for the clinical manifestations.

Management

A review of the 33 cases collected by Straus (*2*), including his own, does not encourage an optimistic attitude concerning migratory foreign bodies. He listed only six survivals, and the pathologist, not the surgeon, was usually the one to remove the object and establish the course of the migration. In World War II, in view of the progress which had been made in thoracic and vascular surgery and in anesthesia between the wars, the thoracic blood vessels and the heart had come within the province of the surgeon, and there were few intravascular foreign bodies which could not be attacked surgically, and with safety. As already stated, there were no deaths in the 78 operations for the removal of intravascular foreign bodies performed at the chest center at the 160th General Hospital.

The three cases of migratory intravascular foreign bodies observed there and just described in detail, together with the cases recorded in the literature, make clear the indications for surgery, which may be stated as follows:

1. *Vascular occlusion.*—This risk is well demonstrated in the gangrene which ensued in the lingular portion of the left upper lobe in case 8. The pathologic process is interesting; theoretically, gangrene should not have occurred with a normal bronchial circulation.
2. *Erosion and hemorrhage.*—These did not occur in this series.
3. *Infection.*—This did not occur in any of the three cases described, but, as Lyle's (*5*) report indicates, it is always a possibility.
4. *Embolism.*—This is the overriding reason for surgical removal of the object, for a fatality is always possible, as a majority of the reported cases indicate, whenever a foreign body enters the blood vessels.

Four technical points proved useful in the management of the cases of migratory intravascular foreign bodies observed at the 160th General Hospital, as well as in a number of other operations on the mediastinum:

1. Splitting of the sternum (case 7) provided good surgical exposure. The bone was carefully approximated with wire at the end of the operation, and the patient did not suffer postoperative pain or shock.
2. Manipulation of the missile from the main right pulmonary artery to the periphery (case 6) permitted surgical manipulations in the relatively safe peripheral zone rather than in the more hazardous hilar region of the pulmonary artery. This technique, which apparently had not previously been described, was certainly less formidable than opening the right horn of the pulmonary artery, removing the missile, and then attempting local reconstitution of the main branch.
3. The digital method of hemostasis, which amounted to using the fingers as a tourniquet (case 8), proved both simple and functional.

4. As soon as the missile was encountered, it was fixed in position, so that migration could not occur during the operative procedure. The patient was also so positioned as to make circumstances unfavorable for migration. The importance of this precaution is evident from the experience in one of these cases (case 6).

One other technical point might be made concerning the case (case 7) in which incision of the innominate artery was necessary. This sort of intervention is always undertaken with some misgivings, since circulatory disturbances in the homolateral arm, as well as contralateral hemiplegia, are possible complications. These accidents, of course, were less to be feared in the age group with which military surgeons had to deal. Nonetheless, their possible occurrence points to the wisdom of restoration of vascular continuity of the innominate artery, rather than ligation, when it must be attacked surgically as in this case.

EXPERIENCES AT THE 155TH GENERAL HOSPITAL THORACIC SURGERY CENTER

Analysis of Data

To complete the picture, the World War II experience of another chest center, at the 155th General Hospital, near Malvern Wells, England, European theater, is briefly summarized. It included the removal of 172 objects from the lungs; 27 from the mediastinum; 37 from the pleura; and 19 from various internal structures, in addition to 63 removed from the deep structures of the thoracic wall. The 172 cases classified as pulmonary included foreign bodies situated in the paramediastinal surface of the lung, either abutting on the mediastinum or partly embedded in the mediastinal pleura.

In four other operations, the foreign body was not removed. In two instances, it lay within the substance of the lung at the hilus but escaped detection because of hematoma formation and pulmonary infiltration. In both of these cases, the object was later removed without difficulty. In the two remaining cases, the object was displaced at operation. In one instance, it lay within the pulmonary artery on one side and slipped into the artery on the opposite side during manipulations. In the other case, it lay in the right ventricle and was displaced into the right auricle and inferior vena cava.

About 93 percent of the retained foreign bodies were high explosive shell fragments. The remaining injuries were caused by small arms fire.

Of the 172 foreign bodies in the lung, 119 were removed by transpleural pneumonotomy. In 48 cases, the free pleura was not entered; the operative procedure could be carried out entirely within a zone of adhesions between the lung and the thoracic parietes. In the remaining five cases, in which a collection of pus was encountered unexpectedly around the object at operation, removal was transpleural, and local marsupialization of the lung was per-

formed in order to minimize the danger of pleural infection. This policy, as already intimated, was successful.

The incision, whenever practical, was placed directly over the foreign body and was always as small as was consistent with satisfactory surgical exposure. A rib resection was never performed when intercostal incision and division of the rib were adequate. When the object could be removed through adhesions which existed between the lung and the pleura, postoperative pleural effusion did not occur, and convalescence was appreciably shortened. The technique employed in such cases was similar to that used in one-stage drainage of an abscess of the lung. Particularly small incisions were required when it was employed.

Of the 27 foreign bodies in the mediastinum, 7 lay in direct relationship with the esophagus; 7 with the pericardium; 6 with the aorta; 2 each with the azygos vein and the innominate artery; and 3 with the vena cava. Seventeen of the objects were removed transpleurally and ten by extrapleural mediastinotomy, the latter procedure being used exclusively when the foreign body lay in the anterior or posterior mediastinum.

The 37 foreign bodies classified as pleural either lay free in the pleural cavity or were embedded superficially in the pulmonary diaphragmatic or parietal pleura and projected into the cavity. In many of these cases, removal was possible through an intercostal incision, without the necessity for rib resection or rib division.

The foreign bodies removed from the deep structures of the thoracic wall involved the peripleural region, the ribs, the intercostal muscles, and the root of the neck immediately adjacent to the dome of the pleura. Except for four cases in which the free pleura was inadvertently entered, all of these objects were approached through small, accurately placed incisions, for which careful preoperative roentgenologic studies had served as guide.

In the remaining 19 cases, 4 foreign bodies were removed from the diaphragm, in which they were completely embedded; 3 each from the liver and the pericardium; 2 each from the pulmonary artery and the heart; 1 from the subphrenic space; and 4 from the vertebral column.

Postoperative management followed standard practices. At first, penicillin was used intrapleurally as well as parenterally. Later, only the parenteral route was employed, since the intrapleural route was thought to increase the frequency and size of postoperative effusion.

There were no pleural infections in the 318 operations in this series, 255 of which were for the removal of intrathoracic foreign bodies. The single death was difficult to explain: A large foreign body, situated posteriorly and superficially in the lung, was removed through a zone of visceroparietal adhesions, without entry into the free pleura. Eight hours after operation, while the patient was lying in bed watching a moving picture being shown in the ward, he suddenly lost consciousness and developed jacksonian seizures involving the right arm and right leg. Death occurred 16 hours later. At autopsy, a cere-

bral hemorrhage was found, the precise etiology of which could not be determined.

Comment

In general, indications for the removal of retained foreign bodies at the 155th General Hospital were conservative, a combination of size (not less than 1 cm. in diameter) and symptoms, of which pain was most prominent. Objects less than 1 cm. in diameter were removed only if they were jagged or irregular or if they were located close to some vital structure and there appeared to be danger of erosion because of mechanical factors or infection.

As the war progressed and the maximum permissible period of hospitalization was progressively reduced, certain patients who would previously have been operated on overseas were returned to the Zone of Interior for surgery. Such cases included those in which the foreign bodies were in, or adjacent to, the heart and great vessels, as well as those in the upper abdomen and in, or adjacent to, the liver. Since most patients with intrapulmonary and intrapleural foreign bodies could be returned to duty overseas within a relatively short time, the proportion of operations in these groups remained fairly stationary throughout the war. Otherwise, operation was not done overseas unless the existence of suppuration or some other complication made the procedure urgent.

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Part III

OBSERVATIONS ON WOUNDS AND DISEASES OF THE CHEST IN THE ZONE OF INTERIOR

CHAPTER IX

Management of the Sequelae of Combat-Incurred Wounds, Zone of Interior

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STATUS OF RETURNING CASUALTIES

The mission of thoracic surgeons in Zone of Interior hospitals as it related to combat-incurred wounds was twofold, (1) reconstructive surgery and (2) rehabilitation of the casualty. From the time the casualty was wounded, the goal of management was the achievement of a completely healed wound and a fully functioning and expanded lung. When these objectives had been accomplished, the casualty was restored to the physical state in which he could perform the duties expected of a soldier returned to duty or could carry on as a civilian discharged from the Army.

Generally speaking, in all theaters, the status of returning casualties depended upon a number of factors, including the character of their wounds and the evacuation policy existing in the particular theater at the particular time, as well as upon the treatment they had received. During the last year of the war, patients received in Zone of Interior hospitals from the Mediterranean and European Theaters of Operations, U.S. Army, had usually been treated definitively at thoracic centers in Italy or the United Kingdom Base. Most of them had also had some form of reconditioning. By January 1945, from 70 to 75 percent were surgically well when they reached the Zone of Interior. They were well nourished and in excellent general condition. This had not been true of thoracic casualties received in the first months of the war from the North African Theater of Operations, U.S. Army, or for the first month or two of the campaign in Western Europe.

With few exceptions, casualties received from the Pacific Ocean areas were never in as good condition as those received from other theaters. Their state of nutrition and their general physical status were usually considerably below the level of similar casualties received from the Mediterranean and European theaters, and until the end of the war they presented a relatively high incidence of hemothoracic empyema and other complications. For this state of affairs, there were three obvious explanations:

1. The environmental differences between the theaters (terrain, heat, disease, insects, fungous infections, and so forth.

2. The longer timelag before initial wound surgery, which was frequently inevitable in the Pacific for logistic reasons.

3. The almost complete lack of experienced thoracic surgeons in all Pacific Ocean areas.

Casualties who required further treatment on their arrival in the Zone of Interior included those with chronic hemothorax or hemothoracic empyema; retained foreign bodies; bronchopleural fistulas; and various defects of the chest wall, including chronic draining sinuses. Those who required no further treatment either were ready for duty after evaluation of their general physical and thoracic status or were at the stage of recovery at which disposition would be possible after 2 or 3 months of reconditioning. Some returned casualties had recovered from their chest injuries but had associated injuries, chiefly peripheral nerve or bone injuries, which prevented their return to duty.

Disposition.—Many casualties who were returned to the Zone of Interior could have been sent back to duty overseas except for the time limits imposed on their convalescence by theater holding policies. Had the war lasted longer, there is no doubt that many others who were evacuated to the United States would have been kept in combat zones and returned to full duty. An attitude of extreme caution concerning these casualties was adopted early in the war for several reasons: The initial severity of many wounds; the recollection of the poor physical and thoracic status of so many thoracic casualties in World War I; and lack of experience with casualties managed under new policies, which made medical officers uncertain about their ability to resume full military duty.

This attitude was apparent in the Zone of Interior as well as in oversea hospitals. In October 1943, Maj. (later Col.) Brian Blades, MC, head of the thoracic surgery service at Walter Reed General Hospital, Washington, D.C., wrote to Lt. Col. (later Col.) B. Noland Carter, MC, Chief, Surgery Branch, Surgical Consultants Division, Office of The Surgeon General, that the disposition of soldiers who had undergone lobectomy was creating some difficulty. More than 50 such operations had been performed at Walter Reed General Hospital during the past year, and about half of the patients had already been returned to duty. It was anticipated that many of the others would soon be ready for disposition. Yet, in spite of the excellent results secured, disposition boards seemed to have a great deal of hesitancy in returning to duty men who had had any sort of chest wound or disease, and line officers had a corresponding hesitancy in accepting them for service. The attitude grew more liberal as the war progressed, but the original hesitancy concerning these patients never entirely disappeared.

CLINICAL CONSIDERATIONS

The management of the sequelae and residua of chest injuries observed in Zone of Interior hospitals was conducted on the same general principles and practices as in oversea hospitals. For that reason, and to maintain con-

tinuity, most complications have been discussed in detail under special headings, including:

Hemothorax (p. 237).
Hemothoracic empyema (p. 272).
Retained foreign bodies (pp. 325 and 353).
Bronchopleural fistulas (p. 169).
Chest wall defects (p. 181).
Draining sinuses of the chest wall (p. 180).
Lung abscess (p. 175).
Hernia of the lung (p. 197).
Diaphragmatic hernia (p. 186).
Traumatic osteomyelitis (p. 179).

Only a few of these conditions need any further discussion from the standpoint of their management in Zone of Interior hospitals.

ORGANIZING HEMOTHORAX

As a rule, more than 8 weeks had elapsed between their wounding and the reception of thoracic casualties in Zone of Interior hospitals. Most hemothoraces that had been correctly treated originally therefore needed little or no attention on their arrival. Figures from the chest center at the Walter Reed General Hospital are typical: Of the first 107 casualties with hemothorax received, 77 were in satisfactory condition, and in 24 of the remaining 30 patients, the lung reexpanded satisfactorily after continued aspiration. This is an unusually high percentage of good results from conservative treatment after such a timelag.

In the six remaining cases, however, an extensive organizing process had occurred, and four of them furnish interesting lessons concerning the proper management of hemothorax. All four wounds had been caused by rifle or machinegun bullets. All wounds were relatively minor as compared with most of the wounds in the other 103 cases in the series, in all of which recovery was without complications. None of the four wounds had originally been of the sucking type. In no instance was the lung damage extensive. No patient had a history of hemoptysis. In every instance, however, aspiration of the chest had been delayed, apparently because the primary wound was not severe and because respirations were not immediately embarrassed. A single case history will serve as an illustration for them all:

Case 1.—This patient, who had sustained a machinegun wound, had his first aspiration 10 days after injury. The procedure was repeated several times, but the largest amount of blood obtained at any aspiration was 180 centimeters. About 30 cc. of air was injected into the chest each time blood was removed.

When this patient was received at Walter Reed General Hospital several weeks after wounding, he was having daily low-grade temperature elevations. He was extremely emaciated. The left chest was flattened, and the expiratory excursion on this side was

greatly limited. Thoracentesis yielded only a few cubic centimeters of dark, bloody fluid. It was necessary to open the chest, evacuate the organized clot, and decorticate the lung.

Comment.—If this man had been treated originally by simple aspiration of the chest soon after wounding, he would probably have been saved weeks of invalidism and a second operation.

Policies of Management

Organizing hemothorax encountered in Zone of Interior hospitals was treated by exploratory thoracotomy. An overlying rib was resected, the cavity was widely opened by means of a rib spreader, and fluid and organized clots were evacuated. If careful inspection showed no need for further surgery, the chest was closed at once. If it showed that the lung could not reexpand because of the pathologic process present, decortication was performed.

Case 2.[1]—A commander of a tank company, wounded in action on 12 July 1944, sustained a penetrating shell-fragment wound of the left chest with a fracture of the eighth rib. Treatment overseas consisted of debridement and closure of the wound on the day of injury, supplemented by two later thoracenteses. When the patient arrived at Halloran General Hospital, Staten Island, N.Y., on 1 September 1944, roentgenograms of the chest (fig. 184A) showed an encapsulated hemothorax on the left side and a shell fragment overlying the seventh intercostal space near the vertebral column. Thoracotomy, performed on 30 October, revealed a cavity containing 150 cc. of old blood clot and a rigid fibrous membrane covering the adjacent portion of the lung. The blood clot was evacuated and the limiting membrane removed, after which the lung was reexpanded. Closure was effected without drainage. Removal of the shell fragment was not attempted. The lung was completely reexpanded on the 15th postoperative day (fig. 184B), and the thoracotomy wound was completely healed at this time (fig. 184C).

Comment.—This case history illustrates the successful management of a small chronic hemothorax by decortication. The rigid limiting membrane revealed at thoracotomy contraindicated any other procedure.

Case 3.—This soldier sustained a perforating wound of the chest on 29 March 1945; the shell fragment lodged in the soft tissues of the back, at the level of the second lumbar vertebra. No immediate effort was made to aspirate the complicating hemothorax. When the patient reached Halloran General Hospital almost 3 months later, examination showed contraction and marked limitation of motion on the right side of the chest. Roentgenograms showed an encapsulated hemopneumothorax in the right axilla.

Because of an attack of malaria, the patient could not be operated on until 21 July 1945. At this time, exploration revealed a cavity of approximately 300-cc. volume, and a rigid fibrous membrane overlying the lung. The membrane was excised and the wound closed without drainage after the lung had been inflated. The postoperative course was complicated by a second hemothorax, which could not be controlled by aspiration because the blood clotted so rapidly. A second decortication was therefore performed on 13 August, after the blood clot had been evacuated. The wound was closed temporarily with a silk and gauze tampon, which was left in place for 7 days. The cavity finally closed on 1 December 1945.

Comment.—The first operation on this casualty was unsuccessful because the blood that had accumulated in the pleura had clotted and could not be removed by aspiration. This is a complication that is always a risk after pulmonary decortication. When post-

[1] This history and the subsequent case histories in this chapter concern patients observed by Maj. Richmond L. Moore, MC, at Halloran General Hospital.

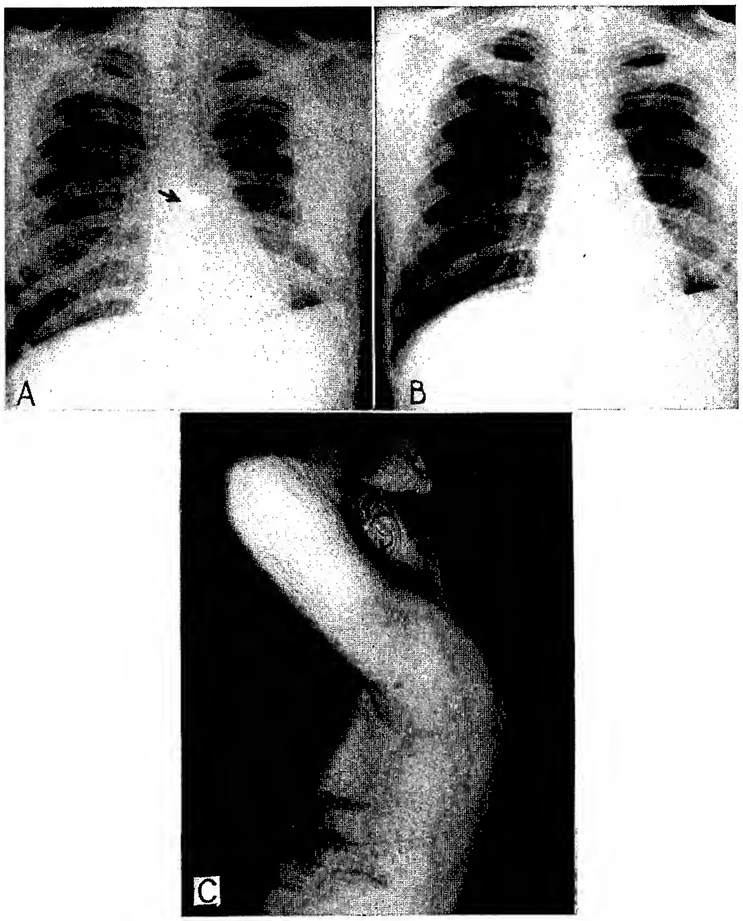

FIGURE 184 (case 2).—Encapsulated hemothorax managed by decortication. A. Posteroanterior roentgenogram of chest showing encapsulated hemothorax on left and metallic fragment in seventh left intercostal space near vertebral column. B. Same, 15 days after evacuation of clot and decortication of lung. Note that lung is completely reexpanded. C. Photograph of patient on 15th postoperative day, showing primary healing of wound.

operative oozing was profuse and difficult to control, as it was in this case, it was safer to establish and maintain some form of closed drainage until the lung had reexpanded and the pleural space was closed.

Case 4.—A large encapsulated hemothorax on the right, with areas of calcification in the thickened membrane on the surface of the lung (fig. 185), was an unexpected finding in a soldier who was evacuated from the Aleutian Islands in the spring of 1944. He had no history of a combat injury to his chest, but he stated that in August 1941 he had been knocked down by an automobile. No roentgenograms of the chest were taken at that time. Operation was recommended and refused.

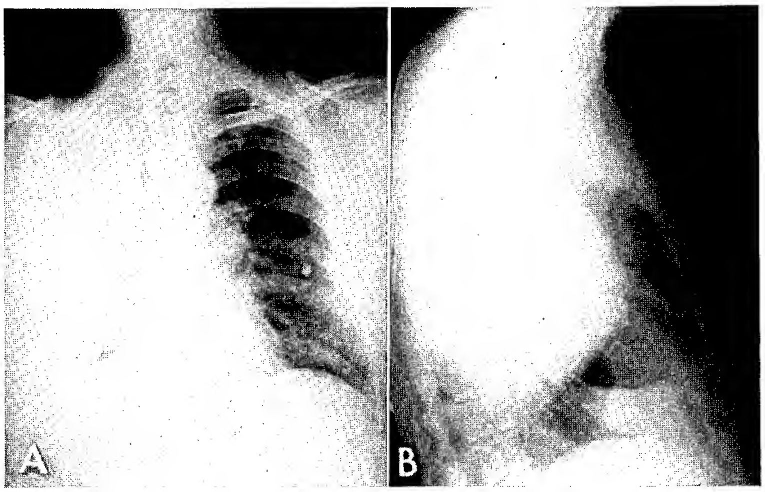

FIGURE 185 (case 4).—Traumatic hemothorax. A. Posteroanterior roentgenogram of chest showing large encapsulated hemothorax on right side. Note areas of calcification in thickened membrane on pulmonary surface. B. Lateral roentgenogram showing same findings.

HEMOTHORACIC EMPYEMA

Empyema, most often originating in an earlier hemothorax, was the most frequent complication of wounds of the chest observed in Zone of Interior chest centers. It decreased in frequency as the war progressed, and it also decreased in seriousness, at least in casualties received from the Mediterranean theater and the European theater. The circumstances of the Pacific Ocean areas, as already pointed out, were different and much more difficult. No matter from what theater they were received, however, few patients reflected the effects of the chronic sepsis and general debilitation so typical of similar patients in World War I.

Early in the war, there were many errors in the management of patients with empyema, including the basic error, failure to treat hemothorax by frequent and vigorous aspiration. In a few instances, initial surgery had been ultraconservative, and revision of the thoracotomy was necessary to provide adequate drainage. In most instances, simple revision, combined with intensive physiotherapy, was sufficient, and complete obliteration of the cavity resulted. If additional surgery was necessary, the patient's general condition was invariably greatly benefited by the preliminary revision.

Also early in the war, an occasional patient was received with closed intercostal drainage in effect. This technique created serious problems during transportation, and drainage was never satsfactory. Later, practically all surgeons overseas abandoned this method and treated empyema by dependent open drainage.

Still another error observed early in the war was the placement of the drainage incision. In October 1943, Maj. (later Lt. Col.) William F. Hoyt, MC, reported from the chest center at Hammond General Hospital, Modesto, Calif., that almost all the patients with empyema received there from overseas had been drained anteriorly and their empyemas had become chronic. Major Blades, transmitting this information to Colonel Carter, stated that the same error was being observed in casualties received at the Walter Reed General Hospital chest center. Reoperation was necessary in all such cases to establish adequate drainage.

The following case history illustrates initial errors of management that led to chronic empyema:

Case 5.—This 24-year-old soldier was struck by a machinegun bullet on 22 September 1944. The bullet entered the left chest posteriorly, between the scapula and spine, and emerged anteriorly in the midclavicular line, about 2 inches below the clavicle. The lung was lacerated and the posterior portion of the fourth rib and the anterior portions of the second and third ribs were shattered. Both wounds were sutured about 30 minutes after injury. The next day, both wounds were reopened and debrided, and the lung was sutured. Both wounds were then closed. After this procedure, the anterior wound became badly infected and a left empyema developed.

When the patient was admitted to Halloran General Hospital on 27 December 1944, he had lost 38 pounds (fig. 186). The left chest was contracted and fixed. The anterior wound was still draining, and the opening in the chest wall was large enough to show a large defect in the lung with multiple fistulas. A drainage tube entered a residual empyema at the site of a previous rib resection.

This casualty was transferred to another hospital for definitive treatment, and his subsequent course is not known.

Decortication

Generally speaking, if a well-drained empyema cavity showed no reduction in volume after a period of 6 weeks, the patient was regarded as a candidate for surgical intervention. The only reliable way of determining the volume of the cavity was by its accurate measurement with injected fluid. This test was omitted only if the patient also had a bronchial fistula.

In the Mediterranean theater, where the operation was introduced in World War II, the optimum time for decortication for empyema was considered to be within a range of 3 to 6 weeks after wounding (p. 286). When patients with empyema were received in Zone of Interior hospitals, their infections had practically always become chronic, and the optimum time for decortication had long since passed. As a matter of necessity, the time was extended, and the results were remarkably good.

In 1945, for instance, 67 delayed decortications were performed for organizing hemothorax or chronic empyema at the chest center at Fitzsimons General Hospital, Denver, Colo., with complete restoration of a functioning lung in every instance; in some cases, the preoperative pulmonary function on the affected side had been as little as 10 percent of the normal. This operation, however, when it was delayed, was not the universal answer to the problem,

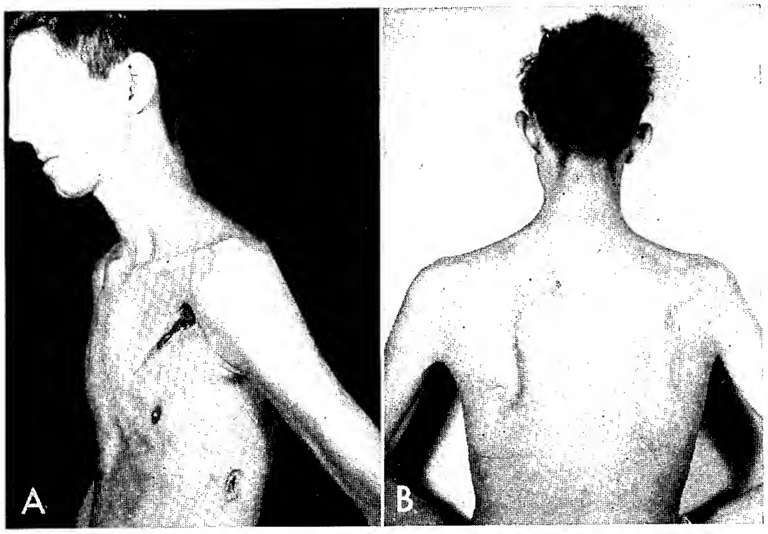

FIGURE 186 (case 5).—Hemothoracic empyema managed by anterior drainage. A. Lateral view of casualty with wound of left chest 4 months after wounding, showing extreme degree of malnutrition, with contraction of left chest. The anterior wound below the left clavicle is the point of exit of the bullet. The wound in the axilla is the site of the rib resection performed 3½ months earlier; it leads into the dependent portion of the empyema cavity. B. Posterior view showing wound in left scapular region which is point of entrance of bullet. This wound was completely healed 3 months after wounding. Note the scoliosis secondary to the contraction and fixation of the left chest.

as is shown by the fact that at this center, over the same period, 51 patients with chronic empyema required some type of thoracoplasty.

When decortication was performed weeks and months after wounding, it was frequently difficult to separate the greatly thickened fibrous membrane from the visceral parietes. Some modifications of the standard technique were therefore introduced. At Brooke General Hospital, San Antonio, Tex., the practice was to separate the membrane from the parietal surface as the first step of the operation. The thickened endothoracic fascia was dissected down to the line of reflection from the parietal to the visceral surface. Once this line was crossed, the adhesions were filmy and readily separated. The peel was then freed from the apex to the diaphragm and anteriorly. After this part of the operation had been completed, the lung was reexpanded under positive pressure, and separation from the visceral pleura was accomplished by sharp dissection.

Patients who had undergone decortication overseas were usually in good condition when they reached the Zone of Interior. If there was any residual, it was usually no more than a small basal empyema, readily corrected by open drainage.

Other Procedures

If delayed decortication could not be carried out without too great risk of damage to pulmonary tissue, other procedures had to be employed. Internal pneumonolysis was frequently used at the chest center at the Walter Reed General Hospital. The operation began with resection of a rib, followed by wide exposure of the entire empyema cavity, as in decortication. If inspection showed that decortication was not practical, the fibroblastic membrane was incised around the periphery of the empyema cavity. Then the incision was carried through the membrane at the juncture of the parietal and visceral portions. The visceral portion was left adherent to the underlying lung, which was cautiously freed from the involved portion of the chest, preferably by blunt dissection with the gloved fingertip or with a dissecting sponge. After the lung had been freed, it was reexpanded by positive pressure (not more than 10 cm. H_2O). As a rule, the empyema cavity was promptly obliterated by this maneuver. Closure was accomplished as in decortication. This operation, which is not a deforming procedure, frequently obviated the necessity for thoracoplasty, which is a deforming procedure.

Physical Therapy

A competent physiotherapist, with special training in the problems of chest conditions, was of great help in the accomplishment of maximum reexpansion of the lung and in overcoming the chest wall deformities commonly seen in chronic empyema and other chest conditions (vol. I).

RETAINED FOREIGN BODIES

It is unfortunate that the Foreign Body Registry, proposed in the 1944–45 report of the Surgical Consultants Division, Office of The Surgeon General, was not instituted, so that permanent records could have been kept on casualties with foreign bodies left in situ. The presumed innocuousness of these objects could then have been established or disproved. The extremely valuable followup information secured by the Peripheral Nerve Registry illustrates what a similar project might have accomplished in thoracic injuries.

Indications for Removal

The indications for removal of foreign bodies in Zone of Interior hospitals were essentially the same as in oversea hospitals. They included their size, their shape (irregularity), the symptoms and signs referable to them, and psychosomatic indications.

Hemoptysis was infrequent. It was observed only twice at the Walter Reed General Hospital chest center and was equally uncommon at other chest centers. Pain, which was the most frequent symptom, was often difficult to evaluate. If the object was peripheral and lay on either the pleural or the

diaphragmatic surface, there was little doubt that it was responsible for the complaint, and its removal was advised. Retained missiles were removed in a considerable number of instances, however, in which there was genuine doubt as to the relation between their presence and the patient's complaint of pain, though there was no doubt at all that until psychosomatic difficulties were thus ended, these men would not again be useful soldiers.

The attitude in Zone of Interior hospitals toward retained foreign bodies was, in general, extremely conservative. Of the first 30 casualties in this category received at the Walter Reed General Hospital chest center, 16 were operated on, 12 because of the size of the objects or because of clear-cut evidence of their responsibility for signs and symptoms, and 4 for psychosomatic reasons. The proportion at other centers was about the same. At Fitzsimons General Hospital, for instance, only 68 foreign bodies were removed from the lung during the entire period of its operation; these were chiefly high explosive shell fragments. In 19 other cases, foreign bodies were removed from the chest wall.

Localization Techniques

In addition to routine techniques of localization (p. 332), certain adjunct techniques were used at the various chest centers. All of the centers found the Berman locator of much supplemental value when foreign bodies were deeply embedded in the parenchyma of the lung or in the mediastinum. It could be used to explore any cavity that could be entered surgically. A constant vibratory sound was heard when the tip of the probe approached, or came into contact with, a retained magnetic object, the volume varying directly with the distance between the object and the probe.

Some surgeons employed a visual-radiopaque technique. A few cubic centimeters of methylene blue or gentian violet were mixed with Lipiodol and injected into the chest wall at the point at which the object was nearest to the surface. Routine roentgenograms were then taken.

The angiocardiographic technique employed at the Walter Reed General Hospital chest center was devised by Lt. Col. George P. Robb, MC, chief of the cardiovascular section. This technique, which was used for the accurate localization of foreign bodies in intimate contact with vessels in the mediastinum, was carried out in three steps:

1. The circulation time from the arm to the tongue was determined by the injection of a solution of Decholin (dehydrocholic acid) and the accurate measurement, by a stopwatch, of the lapsed time between the injection and the patient's report of a bitter taste.

2. The lapsed time was determined between the injection of a solution of ether into the arm and its detection on the patient's breath.

3. After these time factors had been determined, the patient was positioned between a stereoscopic cassette, and angiocardiograms were obtained after the intravenous injection of a concentrated solution of Diodrast (iodopyracet). This radiopaque agent, instead of disseminating immediately in the vascular

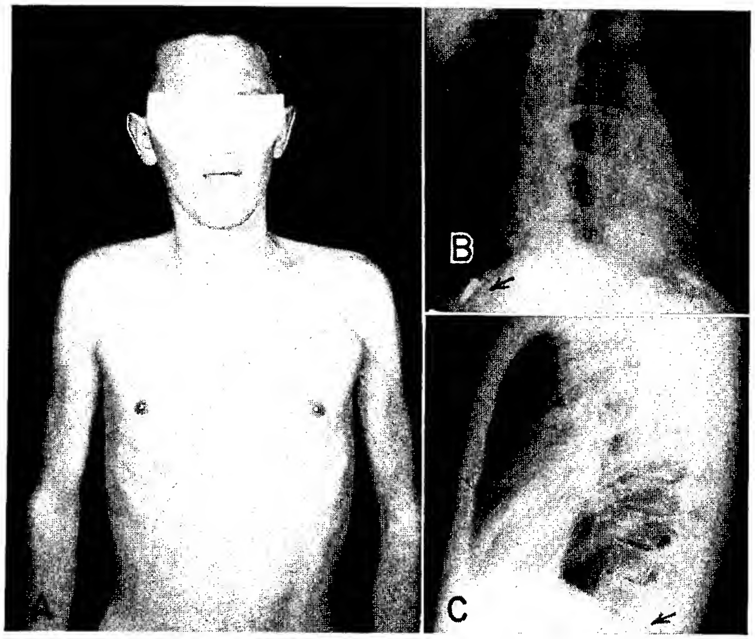

FIGURE 187 (case 6).—Retained foreign body with delayed manifestations due to infection. A. Patient on admission to Halloran General Hospital 14 months after wounding. Scar shows point of entrance of bullet. B. Left anterior oblique roentgenogram showing bullet in right chest opposite tenth intercostal space. C. Lateral roentgenogram showing bullet situated posteriorly just above dome of diaphragm.

system, forms a bolus which can be followed from the point of injection through the cardiovascular system until it is broken up in the peripheral vessels. By evaluation of the previously determined circulation time, the approximate time of opacification of the intrathoracic cardiovascular system could be determined. Separate roentgenograms were made showing contrast filling of the right ventricle and pulmonary arterial tree, the left ventricle and aorta, the right auricle and superior vena cava, and the left auricle and pulmonary veins. With this information, which was usually remarkably precise, it was often possible to determine almost exactly the location of mediastinal foreign bodies in relation to the cardiovascular system in the mediastinum.

Case Reports

Case 6.—A 21-year-old soldier, struck in the right chest by a machinegun bullet on 28 July 1943, made an uneventful recovery. The wound healed satisfactorily, and a complicating hemothorax cleared without aspiration. He had no symptoms referable to his chest until June 1944, when he coughed up a small amount of bright red blood. Another hemoptysis occurred in September. When the patient was admitted to Halloran General Hospital shortly after the second hemoptysis, he was in good general condition (fig. 187A).

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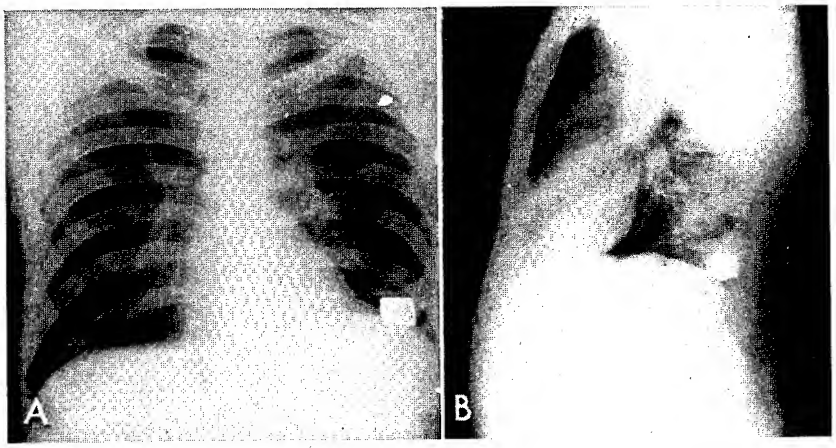

FIGURE 188 (case 7).—Retained foreign body without symptoms. A. Postero-anterior roentgenogram of chest 10 weeks after wounding, showing large metallic fragment in left chest at level of tenth dorsal vertebra. Another smaller fragment is seen outside the chest cavity in the axillary tissues. B. Lateral roentgenogram taken at the same time, showing the posterior location of the larger fragment.

Roentgenograms (fig. 187B and C) showed a .25-caliber bullet situated posteriorly on the right side, at the level of the tenth intercostal space. Roentgenograms made after the instillation of Lipiodol showed no evidence of bronchiectasis.

The bullet was removed on 13 October 1944. The space which it occupied, which communicated freely with the bronchial tree, contained a small amount of necrotic material, culture of which revealed hemolytic *Staphylococcus aureus*. Convalescence was satisfactory except for a small empyema, which healed rapidly after resection and drainage.

Comment.—As this case demonstrates, a foreign body may be embedded in the lung for many months before it causes symptoms. The patient's history suggests that the hemoptyses which finally occurred were secondary to the staphylococcic infection.

Case 7.—This soldier received multiple penetrating wounds of the left chest on 28 July 1944. On 30 July, all wounds were debrided and several readily accessible foreign bodies were removed. When he arrived at Halloran General Hospital on 9 October, he was pale and weak and showed evidence of considerable weight loss. The temperature was 103°F., the pulse 120, and the respirations 30. The red blood cell count was 2,270,000 per cu. mm. and the white blood cell count 3,900 per cubic millimeters. The hemoglobin (Sahli) was 7.5 gm. percent. Roentgenograms of the chest (fig. 188) showed a metallic fragment, about 2 by 3 cm., in the posterior portion of the left lung at the level of the tenth dorsal vertebra.

Treatment consisted of penicillin, repeated blood transfusions, and vitamin therapy. A subcutaneous abscess in the left scapular region was drained on 19 October 1944, and 3 pieces of woolen shirt were evacuated with 25 cc. of purulent fluid. Culture of the exudate showed *Bacillus coli* and nonhemolytic *Staph. aureus*. After drainage of the abscess, the temperature quickly fell to normal, and convalescence was satisfactory except for an attack of malaria, which responded well to Atabrine (quinacrine hydrochloride). By the middle of November, the patient had gained 19 pounds, and his red blood cells had risen to 4,870,000 per cubic millimeters. The time was considered optimum for removal of the fragment from the left lung, but since he had now become transportable, he had to be reported to the hospital registrar for transfer to another institution for definitive care.

granulation tissue to contract, with resultant exposure of the cut edges of previously healthy rib or cartilage.

The most satisfactory technique of repair was as follows: The sinus tracts were fully exposed, with due care to preserve as much healthy skin as possible. The affected cartilages were excised down to healthy tissue, and all foreign material, including sutures, was removed. The wound was then dressed with petrolatum-impregnated gauze and left open. As a rule, clean granulations were observed in 4 to 7 days. As soon as they were evident, the wound surface was covered with a split-thickness skin graft. This simple technique usually resulted in prompt healing and greatly reduced the period of hospitalization required when more complicated techniques were used.

ASSOCIATED WOUNDS

Associated wounds in patients with thoracic injuries referred to chest centers were most often regional fractures and regional nerve injuries. Many ribs were splintered and many scapulas shattered by missiles, and some surgeons thought that such injuries accounted for more residual pain than ordinary fractures. Major Hoyt, at Halloran General Hospital, had the impression that casualties with such fractures took a considerable time to regain their mental equilibrium. Many of them referred repeatedly to the difficulty in breathing they had experienced soon after injury. When hemoptysis was added to the respiratory embarrassment, the experience seemed particularly frightening. These patients required a great deal of individual attention, and their physical recovery progressed more rapidly as their mental status improved.

A number of chest wounds were complicated by nerve injuries, particularly injuries of the brachial plexus. The position at wounding accounted for these injuries. If the soldier was crawling forward on his hands and knees, or was advancing in a bent over position, the supraclavicular area was presented as a target. The entering missile fractured the clavicle and emerged between the scapula and spine or the scapula and ribs. The location of the wound was such that the brachial plexus was implicated in it, and partial paralysis of the arm and hand resulted. Many of these patients had to be transferred to neurosurgical centers for treatment after their thoracic injuries were completely healed.

CHAPTER X

Surgical Aspects of Diseases of the Chest

Brian Blades, M.D., B. Noland Carter, M.D., and Michael E. DeBakey, M.D.

BRONCHIECTASIS

Incidence

Army statistics testify to the importance of bronchiectasis among diseases of the chest. Admissions during 1942–45 (table 15) numbered 6,207, of which 5,164 were to hospitals in the continental United States. During this same period, there were 12 deaths in the U.S. Army in which bronchiectasis was the underlying cause, and, more important from the standpoint of Army manpower, there were 4,487 disability separations for this cause.

TABLE 15.—*Admissions for bronchiectasis in the U.S. Army, by area and year, 1942–45*
[Preliminary data based on sample tabulations of individual medical records]
[Rate expressed as number of admissions per annum per 1,000 average strength]

Area	1942-45		1942		1943		1944		1945	
	Number	Rate	Number	Rate	Number	Rate	Number	Rate	Number	Rate
Continental United States	5, 164	0. 35	980	0. 37	2, 185	0. 42	1, 214	0. 31	785	0. 27
Overseas:										
Europe	381	0. 09	17	0. 20	49	0. 18	160	0. 10	155	0. 07
Mediterranean [1]	174	. 12	4	. 17	75	. 16	70	. 11	25	. 07
Middle East	18	. 12	1	. 17	8	. 15	9	. 19	------	-----
China-Burma-India	48	. 11	4	. 46	6	. 15	23	. 14	15	. 07
Southwest Pacific	176	. 10	15	. 21	24	. 13	62	. 11	75	. 07
Central and South Pacific	159	. 13	18	. 12	55	. 19	56	. 13	30	. 08
North America [2]	42	. 09	17	. 17	17	. 09	8	. 06	------	-----
Latin America	40	. 10	15	. 15	21	. 17	4	. 05	------	-----
Total overseas [3]	1, 043	0. 10	93	0. 16	255	0. 15	395	0. 10	300	0. 06
Total Army	6, 207	0. 24	1, 073	0. 33	2, 440	0. 36	1, 609	0. 21	1, 085	0. 14

[1] Includes North Africa.
[2] Includes Alaska and Iceland.
[3] Includes admissions on transports.

Even granting the assumption that not every admission for bronchiectasis represented an actual instance of this disease, the numbers are sufficiently large to indicate the extent of the problem. The figures also suggest the possible incidence of this disease in the general population: These 6,207 patients were in a selected age group of men, who had passed the physical examination and roentgenologic examination for induction into the Army. The number of draftees who were rejected for service because bronchiectasis was detected is undoubtedly several times greater.

The manifestations of bronchiectasis were essentially the same in military as in civilian practice and call for no special discussion. They were chiefly dependent upon the degree of sepsis, which in turn was chiefly dependent upon the adequacy of bronchial drainage. When the disease was advanced, the destructive changes were always permanent and irreversible and could be managed only by extirpation of the involved tissue.

The following material, which can be assumed to be typical, is based on an analysis of 390 consecutive patients with bronchiectasis treated at Percy Jones General Hospital, Battle Creek, Mich., and the chest center at Kennedy General Hospital, Memphis, Tenn., during World War II by Maj. Earle B. Kay, MC; Maj. (later Lt. Col.) Richard H. Meade, Jr., MC; and Maj. Felix A. Hughes, Jr., MC (*1*).

Diagnosis

Diagnosis was based on:

1. Roentgenologic examination, repeated as necessary.

2. Bronchography, with outlining of all five pulmonary lobes. This measure had to be employed with caution, for it sometimes disclosed minor degrees of dilatation on which a diagnosis of bronchiectasis was based, in the absence of clinical symptoms. For this, there was no warrant.

3. Bronchoscopic examination, to determine the source of the exudate. If the bronchial mucosa seemed unduly inflamed, the possibility of bronchial occlusion secondary to a retained foreign body or a neoplasm had to be considered and eliminated.

4. Bronchospirometric studies, which were important if the disease was bilateral, to determine which was the worse side (p. 421). It was also important to determine the pulmonary reserve of the uninvolved lung if dyspnea was a symptom and to establish the extent of functional tissue in borderline cases.

Differential diagnosis chiefly concerned the reversible bronchial dilatations that sometimes followed an acute attack of respiratory infection, particularly atypical pneumonia. In October 1943, Maj. (later Col.) Brian Blades, MC, wrote to Lt. Col. (later Col.) B. Noland Carter, MC, that Major Meade had reported this complication at the Kennedy General Hospital chest center and that it was also being observed at the chest center at Walter Reed General Hospital, Washington, D.C. The temporary nature of the bronchial dilatation

in these cases could be demonstrated by repeating the bronchogram a few weeks later; the bronchial configuration then usually showed a complete return to normal. Bronchoscopic examination was also useful. Differential points were the marked edema and generalized inflammatory reaction in the postpneumonia patients, lesser friability and vascularity, and absence of the characteristic odor of the purulent sputum of bronchiectasis.

Conservative Management

The high hopes originally entertained for the use of penicillin in bronchiectasis were not fulfilled. It was never likely that they would be. This is a disease characterized by bronchial and bronchiolar destruction, permanent bronchial dilatation, chronic infection, and marked sepsis. In advanced stages, the normal bronchial architecture is replaced by less specialized tissue, a pathologic change that explains the recurrent periods of exacerbation and the chronic state of sepsis that characterize it. Penicillin was of considerable value in the treatment of recurrent pneumonic episodes as well as in decreasing the sepsis and toxicity of the interval stages. Occasionally, it changed the character of the sputum. It frequently decreased the cough and sputum and increased the sense of well-being. These improvements lasted, however, only as long as penicillin was administered. When administration was discontinued, they were promptly lost.

At the Kennedy General Hospital chest center, 45 patients with advanced bronchiectasis were treated with intramuscular injections of 25,000 units of penicillin every 3 hours for 1 or 2 months and, in 4 cases, for 3 months. The improvements just listed occurred in about two-thirds of the patients, usually during the first few weeks of treatment. Regression occurred when penicillin was discontinued, and no patient with advanced bronchiectasis had any permanent benefit from the treatment.

Intratracheal penicillin was used in another 45 patients with bronchiectasis, with somewhat better results. The seven patients with minimal disease had almost complete relief, and definite improvement occurred in two-thirds of the remaining patients.

Indications for Lobectomy

Neither penicillin nor any other form of conservative therapy was the solution of the problem of advanced bronchiectasis. Only surgery provided the answer. The decision to resort to it depended upon the extent of destructive changes, the physical evidences of chronic toxicity, and the amount of disability and invalidism. Of particular importance was the evaluation of the patient as a whole, including not only his present symptoms but his past history, with special reference to the increasing frequency or severity of acute episodes.

Operation was never indicated in patients with minimal disease, who could be treated conservatively with good results. It was not indicated in patients who had no clinical evidence of the disease, even though roentgeno-

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grams showed varying degrees of apparently permanent bronchial dilatation. Nor was it indicated in patients with disease of all five lobes; they were beyond surgical help.

Bilateral bronchiectasis, which was present in about 30 percent of the patients observed in World War II, was not considered a contraindication to surgery. Past experience had shown that those with advanced disease on one side and minimal disease on the other were usually greatly improved by operation on the more severely involved side. If the disease was extensive on both sides, operation was still considered indicated as long as (1) the right upper lobe and (2) the upper aspect of the left upper lobe were free from disease and the cardiorespiratory reserve was adequate.

These indications were followed in the 184 lobectomies in this series, in 36 of which the disease was bilateral and in 6 of which bilateral lobectomy was performed. In another case, the right middle and lower lobes had been removed earlier, and the left lower lobe and the lingula of the left upper lobe were removed later (p. 420).

Preoperative Preparation

Operation was not scheduled until 4 to 6 weeks had elapsed after bronchography, to allow time for the elimination of the injected iodized oil. In the absence of this precaution, a postoperative pneumonitis was a possibility.

Preoperative preparation was extremely careful and painstaking. It consisted of the following measures:

1. Patients who had been ill over a long period of time had a detailed medical study, to eliminate possible cardiac, hepatic, and renal complications.
2. An otolaryngologic examination was made, and any infection found received the proper treatment. Sinusitis was treated by nebulized penicillin.
3. The diet was high in vitamins and calories, and supplementary vitamin therapy was used as necessary. The vitamin C content of the blood was brought to normal.
4. The plasma protein components of the blood were also brought to normal by supplementary protein components in the diet or by blood transfusions if they were indicated. A blood transfusion was always begun when operation was started and was usually continued throughout its course, in the amount of 1,000 to 1,500 cubic centimeters.
5. A physiotherapist explained and demonstrated the breathing exercises to be used during the entire postoperative period.
6. If postural drainage proved useful, it was employed three or four times a day.
7. If sputum was copious and bronchitis severe, a course of intratracheal penicillin, given for 7 to 14 days, was frequently helpful in reducing the amount of sputum.

8. Intramuscular injections of penicillin were begun the day before operation. When penicillin became available in preparations of beeswax and peanut oil, single injections of 300,000 units were given daily before operation, usually for 3 to 7 days, and were continued after operation until the temperature was normal.

Technique

The individual ligation technique was used in 182 of the 184 lobectomies in this series; only the first 2 were performed by the mass ligation technique. If purulent secretions were excessive, the bronchus was closed as soon as possible, but seldom before the arteries were divided. The inferior pulmonary vein was always the last vessel ligated. It was thought that the danger of embolism from involved lobes was less important than the technical disadvantage of permitting the lobe to become engorged.

Pleuritic adhesions between the upper lobe and the chest wall were cut. If they were allowed to persist, they might prevent the upper lobe from readily readjusting to the larger space now available to it.

In all partial pulmonary resections, the pleura was drained by an airtight catheter connected to water-seal suction. Drainage was usually maintained for 48 hours. Bronchoscopic aspiration was performed routinely at the end of the operation.

At the end of the operation, roentgenograms were taken and immediate corrective measures were instituted if they showed atelectasis or if reexpansion of the remaining lung tissue was not satisfactory.

Postoperative Routine

The usual routine of postoperative care was followed after lobectomy, with special emphasis upon the following measures:

1. Oxygen was administered for the first 12 to 24 hours.

2. If the patient complained of tightness in the chest during the early postoperative period, temporary phrenic nerve paralysis was performed. This was a particularly important precaution if an emphysematous lobe had been removed, to prevent overdistention of the remaining lobe (lobes), as well as in high lingulectomies or middle lobe lobectomies performed in combination with lower lobe lobectomies.

3. The patient was usually ambulatory by the fifth day and was permitted out of bed earlier if he had difficulty in voiding.

4. Daily roentgenograms were taken at the bedside, to keep constant check on the remaining lobe or lobes.

5. When the hemithorax was satisfactorily filled with the remaining lung tissue and the patient's general condition was good, he was given a convalescent furlough. His disposition was determined on his return to the hospital.

Mortality and Complications

The single surgical death in this series occurred in the fourth of the 184 lobectomies. The patient had had bronchiectasis of the right lower lobe for many months, with repeated hemoptyses. Anesthesia was trying. It was hard to maintain a clear airway. The operation was technically difficult and time consuming. It is doubtful that this fatality, which was attributed to cerebral and pulmonary edema, would have occurred if the patient had been operated on later in the series.

The complications in these 184 lobectomies were as follows:

Significant shock from blood loss occurred in only one case.

Postoperative atelectasis occurred in five cases. Its infrequency was the result of the vigorous endeavors to keep the bronchi free of secretions by early movement, frequent voluntary coughing, and aspiration of retained secretions as necessary. In one case, however, atelectasis was alarming. This patient had had the right middle and lower lobes removed at one operation, and the left lower lobe and lingula at another sitting 6 months later. On the third day after the last operation, atelectasis of the remaining portion of the left upper lobe developed and persisted to some degree for the next 3 days. During this time, the patient was maintained only on the right upper lobe, with repeated intratracheal aspiration and the intermittent use of intranasal oxygen. Recovery thereafter was uncomplicated.

Hemothorax developed in two cases, probably because of injury of the intercostal vessels when the thoracotomy tubes were inserted.

Bronchopleural fistula with resulting empyema occurred in 20 cases, all early in the series. There were only 5 such complications in the last 100 lobectomies. Postlobectomy empyema was not a serious problem at any of the thoracic surgery centers. It was thought that careful surgical technique and prompt reexpansion of the remaining lung had more to do with this than did the use of penicillin.

Jaundice developed in six cases, whether secondary to blood transfusion or as the result of concomitant hepatitis is not clear; a number of other patients developed hepatitis at about this time.

One patient had a cerebrovascular accident, probably from a septic embolus. He was treated with penicillin and streptomycin. Six weeks later, a trephine operation was performed, and a small, sterile cystic cavity was evacuated. Recovery followed. Penicillin was given by vein during operation in subsequent cases, to reduce the likelihood of this complication.

There was no complication from the contralateral lung in any patient with bilateral bronchiectasis, probably because in these cases, the postoperative regimen was particularly rigid.

Bronchospirometry

Ten patients in this series upon whom bronchospirometric studies were performed before operation had an average oxygen consumption on the affected side of only 37 percent of the total and an average ventilation of 44 percent of the total. These figures show the effects of bronchiectatic destruction of tissue on the pulmonary function. They also show that the efficiency of oxygen absorption into the alveolar capillaries or through the alveolar membrane is even more impaired in this disease than is the ability to ventilate the lung.

In one instance, bronchospirometric studies on a patient with bilateral disease showed that oxygen consumption was 61.1 percent on the more severely impaired side and only 38.9 percent on the other side, on which there was thought to be only minimal disease in the right upper lobe. Evidently, destructive changes not apparent by roentgenogram or bronchogram were present in the supposedly good lung. Two patients, not included in this series, were found to have such copious amounts of sputum and such a degree of bronchial obstruction that there was no oxygen absorption at all on the affected side.

These studies indicate (1) that, in many instances, the bronchiectatic lobe contributes very little to the oxygenation and gaseous exchange of the blood circulating in the pulmonary tissues; (2) that the blood returns to the heart unoxygenated and with a high carbon dioxide content; and (3) that these phenomena are responsible in large measure for the cyanosis and dyspnea observed in bronchiectasis. Only by removal of the bronchiectatic tissue can blood be circulated through the alveoli, with proper oxygenation and diffusion of gases.

Postoperative bronchospirometric studies in 26 cases in this series showed that the pulmonary function of the remaining lung tissue on the affected side was largely dependent on the presence or absence of postoperative pleural complications (figs. 190, 191, 192 and 193). In none of these cases was the pulmonary function significantly impaired when recovery was uneventful; in numerous instances, it was within normal limits 2 or 3 months after operation. That good results persist is suggested by the fact that function was normal in two other patients examined, respectively, 1 year and 3 years after lobectomy.

Results

The good results in this series were unquestionably influenced by the fact that practically all of the patients were excellent risks as compared with candidates for surgery in civilian practice. Their disease was such that it could be cured only by pulmonary resection, and the risks they underwent were so small compared to the risks of persisting disease that operation was recommended without hesitation in every case in which it was indicated.

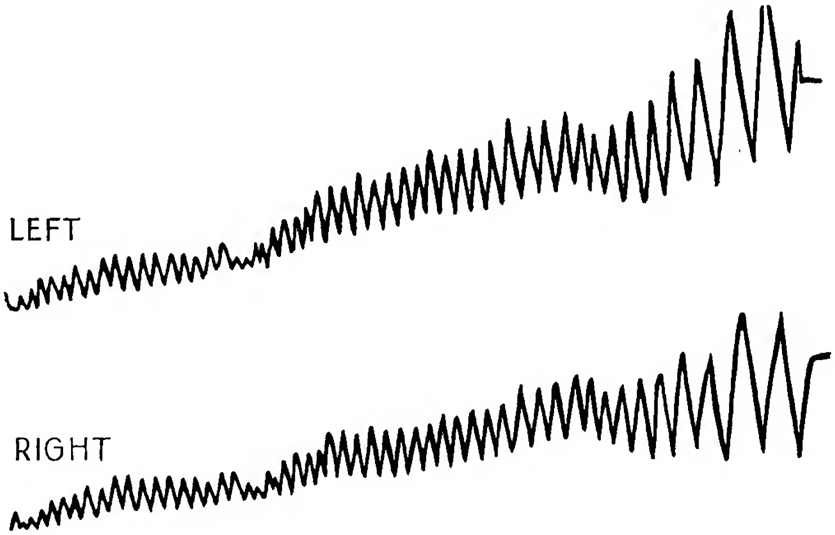

FIGURE 190.—Bronchospirometric tracing 1 month after left lower lobe lobectomy for bronchiectasis. Left side now contributes 53 percent of total oxygen consumption and 52 percent of total ventilation. Convalescence was entirely uneventful.

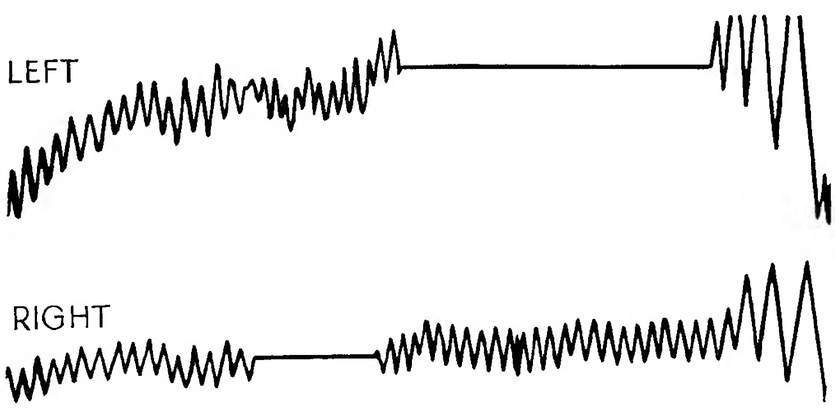

FIGURE 191.—Bronchospirometric tracing 7 weeks after left lower lobe lobectomy for bronchiectasis in patient with residual dysfunction of right lung secondary to pneumonia and empyema. The decreased pulmonary function secondary to pleural thickening on this side is evident from the fact that the left side contributes 76.4 percent of the total ventilation.

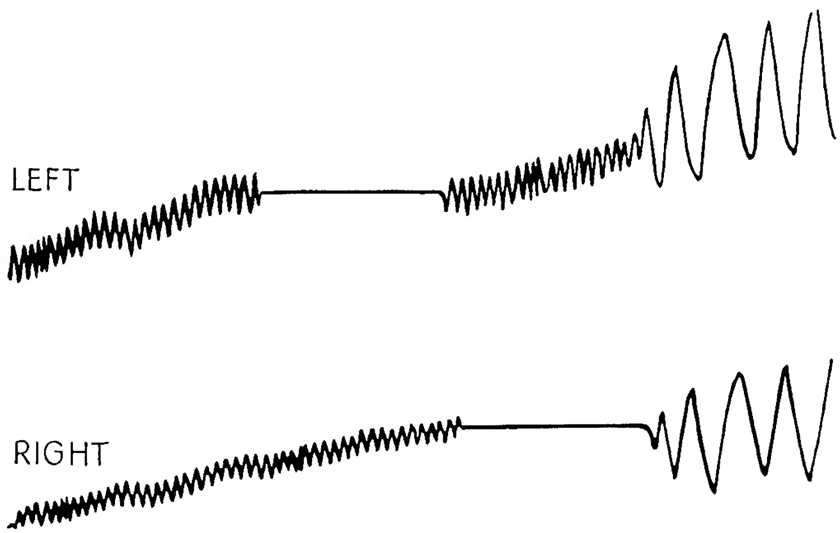

FIGURE 192.—Bronchospirometric tracing 8 weeks after right middle and lower lobe lobectomy for bronchiectasis. The phrenic nerve was crushed 8 days after operation to prevent overdistention and emphysema of upper lobe. The right side now contributes 47 percent of total oxygen consumption and 43 percent of total ventilation.

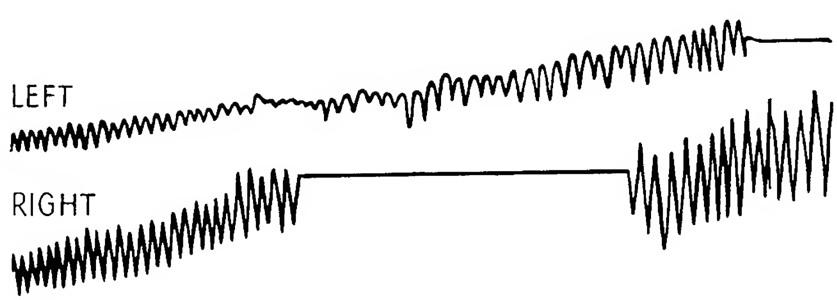

FIGURE 193.—Bronchospirometric tracing 7 weeks after resection of left lower lobe and lingula of the upper lobe for bronchiectasis. The phrenic nerve was crushed 3 days after operation to prevent overdistention of remaining segment of upper lobe. Remaining segment of upper left lobe now contributes 33.3 percent of total oxygen consumption and 26.3 percent of total ventilation.

Administrative Considerations

When bronchiectasis was clearly not "line of duty," as manifested by a history of previous symptoms pointing to it, disposition could be accomplished at any hospital at which authorized disposition boards were held.

All patients with bronchiectasis considered to be line of duty were transferred to a thoracic surgery center, where treatment was carried out and disposition was effected by consultation between the medical and the surgical services. The policy was to discharge men who did not wish to be operated on or in whom operation was contraindicated. Those with extensive bilateral disease were given medical discharges. Those with advanced disease not suitable for surgery were usually transferred to a Veterans' Administration hospital.

Although many men were returned to full duty after lobectomy, there was some hesitancy all through the war about returning to duty, or accepting for duty, any man who had any type of thoracic disease. This problem first came up in October 1943, after more than 50 lobectomies had been performed at the Walter Reed thoracic surgery center, and Major Blades wrote to Colonel Carter about it.

PULMONARY TUBERCULOSIS

Surgical Procedures

In World War I, pulmonary tuberculosis was a major problem, as might have been expected, for both roentgenologic and screening techniques were crude by modern standards. In World War II, the efficient screening and case-finding methods that had been developed between the wars were put to good use, and tuberculosis in the Armed Forces was never a major concern.

The finding of active disease in a soldier, at least in the first years of the war, was considered almost synonymous with his permanent release from active duty. As the war progressed, however, this concept began to be altered, and surgery was employed in occasional, carefully selected cases, with remarkably good results.

A listing of the procedures accomplished at the chest center at Fitzsimons General Hospital, Denver, Colo., in 1944 and 1945 shows interesting changes in the procedure employed, as well as an increasing interest in surgery for tuberculosis (table 16).

All patients selected for surgery were first carefully considered by the medical board of the hospital, and the responsibility of the chest center for them varied according to the operation. Patients who underwent only phrenic emphraxis were brought to the operating room from the medical ward and returned to the medical ward immediately after the operation. Patients who underwent pneumonolysis were transferred to the surgery section the afternoon

TABLE 16.—*Operations for pulmonary tuberculosis, Fitzsimons General Hospital thoracic surgery center, 1944–45*

Procedure	1944–45	1944	1945
Thoracoplasty	213	139	74
Phrenic emphraxis	490	226	264
Intrapleural pneumonolysis	25	23	2
Open pneumonolysis	72	----------	72
Lobectomy	40	12	28
Segmental resection	7	----------	7
Pneumonectomy	5	2	3
Partial pneumonectomy	3	----------	3
Decortication	5	----------	5
Total	860	402	458

before operation. A roentgenogram was taken at once to determine the degree of pneumothorax present.

The patients were held on the surgical ward after operation only until the intrapleural pressure was well stabilized, which was usually within 72 hours. Candidates for other operations were transferred to the surgery section before operation and held on it until their immediate convalescence was complete.

Pulmonary resection for tuberculosis was introduced at this center in 1944. There was 1 death in the 12 operations, from massive postoperative spread of the process. The patient was a poor surgical risk, with bilateral cavitary disease, and left upper lobectomy was performed in the desperate hope of controlling it. A mixed empyematous process developed in another case after operation, but the patient made a good recovery, and there was no spread of the disease in any other case. All other patients recovered smoothly. These results were considered so encouraging that the policy was continued and extended in 1945. There were no deaths in the 28 lobectomies performed in that year, and postoperative spread of the disease occurred in only one case. The center closed before long-term results of lobectomy could be observed, but the immediate results were considered most encouraging.

It was not always easy to select patients for lobectomy. In general, the procedure was limited to chronic disease with localized involvement which had not responded to standard collapse therapy.

The results of pneumonectomy were not encouraging, which was not unexpected, for all operations were done for advanced disease involving the entire lung. All the patients were extremely poor surgical risks, and operation was a last resort. There were two deaths in the three operations performed in 1944.

Tuberculomas.—The seven segmental pulmonary resections performed at the Fitzsimons General Hospital chest center in 1945 were all for tuberculomas. These neoplasms were formerly considered extremely uncommon. Routine

roentgenologic examinations of men in service at induction, at separation, and sometimes more often, showed that they were by no means as uncommon as they had originally seemed.

Most tuberculomas were asymptomatic, but careful inquiry into the previous history often revealed positive or suspicious stories of active disease. The majority of the masses were solitary, but in a number of instances, satellite fibrocaseous nodules were associated with the larger growths, particularly in the upper lobes.

When a tuberculoma was diagnosed, its presence was regarded as an indication for surgery. These lesions have dangerous potentialities for breaking down and spreading. At operation, they are usually found to be more extensive than roentgenologic examination has suggested. Finally, neither roentgenologic examination nor any other measure is sufficiently accurate to differentiate them from bronchogenic carcinoma.

If bacteriologic examination revealed acidfast bacilli, medical treatment was employed before operation. The possibility of endobronchial disease always required investigation before operation; it was unusual, but preoperative treatment was necessary if it was found.

Excision was usually possible by wedge resection, with conservation of as much lung tissue as possible. Lobectomy was necessary if the lesions were large or if there were satellite nodules.

Recovery was usually smooth, and most operations could be considered successful. The postwar experience has shown that many patients treated by excision of tuberculomas can be returned to full military duty.

Tuberculosis Complicating Combat-Incurred Wounds

Attention has been called to an unusual case in the Mediterranean theater in which recovery was complicated by activation of latent tuberculosis (p. 165). The following similar case was observed at Halloran General Hospital, Staten Island, N.Y., by Maj. Richmond L. Moore, MC:

Case 1.—A private in the infantry was struck in the left lower chest on 2 May 1944, in England, by a fragment from an accidentally exploded 60-mm. mortar shell. When he was seen in a general hospital 2 hours later, he was in moderate shock and was complaining of severe upper abdominal pain. The upper abdomen was rigid and tender, and there was beginning dullness in both flanks. The thoracic wound, which was about 15 cm. long, was in the left midaxillary line, at the level of the tenth intercostal space. A portion of the spleen had herniated through it. Roentgenograms of the chest and abdomen showed neither pneumothorax nor foreign bodies.

Exploration of the abdomen through a T-shaped incision revealed a ruptured spleen, a 7-cm. rent in the left leaf of the diaphragm, perforations on the greater and lesser curvatures of the stomach, and a puncture wound on the inferior surface of the left lobe of the liver. The peritoneal cavity was full of blood mixed with gastric contents. The operation consisted of splenectomy and repair of the perforations in the stomach and the diaphragm. The puncture wound of the liver was not explored. The wound of the chest wall was debrided before closure, which was complete.

Roentgenograms on 12 May showed a left hemopneumothorax, but the chart bore no record of treatment by aspiration. On 15 May, 100 cc. of purulent exudate was evacuated from the upper half of the abdominal wound.

Both wounds then healed well, and convalescence was uneventful until the latter part of June, when the patient began to run an intermittent septic fever, for which no cause was discovered. He was received at a general hospital in the Zone of Interior on 8 August. On 22 August, aspiration of the chest yielded 300 cc. of thick pus. The following day, 4 cm. of the ninth rib was resected, and drainage was established.

When the patient was received at Halloran General Hospital, on 19 September, there was a discharging sinus at the site of the rib resection. Roentgenograms of the chest on the following day, after instillation of 20 cc. of Lipiodol, revealed a triangular cavity at the left base, measuring 3 by 6 centimeters. A metallic foreign body 7 by 15 mm. was in the upper abdomen, in the region of the liver.

Drainage was obviously inadequate, and a second thoracotomy was done on 25 September, with resection of the eighth and ninth ribs and the intervening intercostal muscle bundles and pleura. Microscopic examination of the excised sinus tract showed numerous tubercles with central necrosis and borders of granulomatous tissue. The diagnosis of tuberculosis was confirmed by examination of a second specimen on 27 October.

Another persistent sinus developed after the second thoracotomy and showed no tendency toward healing in spite of vigorous local treatment. On 3 January 1945, roentgenograms of the chest after instillation of Lipiodol showed an empyema cavity about 7 by 2 cm. and a bronchopleural fistula.

At a third operation on 2 May 1945, exploration showed that the sinus extended deep into the substance of the lung. The tissue excised at this operation included the surrounding zone of scar tissue, all of the regenerated bone surrounding the external opening of the sinus tract, and additional segments from the stumps of the eighth and ninth ribs. Sections of tissues stained by the Ziehl-Neelsen technique showed acidfast organisms.

The lung apparently healed rapidly, but another persistent sinus appeared. At exploration on 22 June, it was found to extend through the lung to the diaphragm. It was thoroughly excised by the radical technique used at the operation on 2 May. The resulting extensive defect in the chest wall was closed by undermining and approximating the muscles and subcutaneous tissue. A small rubber tube was left in the center of the wound between the lung, diaphragm, and chest wall.

Healing was rapid and satisfactory. The drainage tube was removed on 25 July, and 4 days later, the sinus was completely closed, as it was when the patient returned on 5 September 1945 from a 30-day convalescent leave. Although he had gained 60 pounds since the second thoracotomy on 25 September 1944 and was in excellent general condition (fig. 194), he was considered unfit for further military duty and was separated from service.

The tissues removed at this operation again showed classical tubercles with central necrosis, rimmed by epithelioid cells and lymphocytes and the typical Langhans type of giant cell.

Comment.—This man received excellent surgery within 3 hours of his injury, and his recovery must be attributed to it. It was wise not to attempt to remove the shell fragment in the liver or to explore the chest, for his condition was poor and his blood pressure fell to 0 on the operating table. Complete primary closure of the chest wound after debridement was, however, contrary to military teachings. Furthermore, had the hemothorax evident 6 days after wounding been treated by aspiration, it is highly probable that the empyema which developed would have been prevented.

The particular point of interest in this case is the diagnosis of tuberculosis in the tissues at the site of injury. Careful inquiry showed nothing in the previous history to suggest acidfast infection of any kind. The tuberculous infection supplied an adequate explanation for the chronicity of the process and the repeated failures to obtain satisfactory

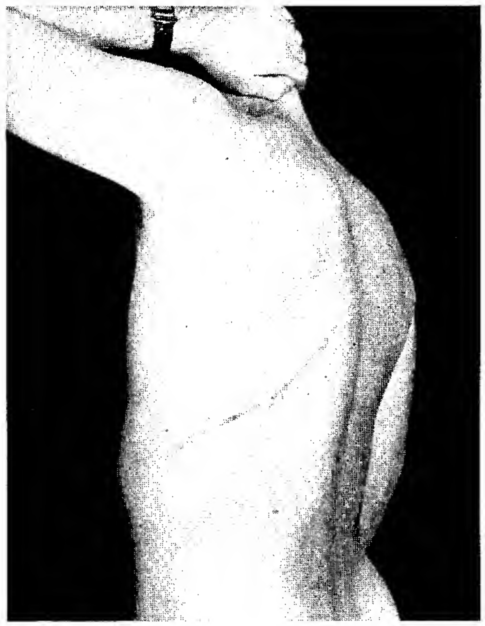

FIGURE 194 (case 1).—Patient after final closure of tuberculous sinus complicating thoracoabdominal wound 16 months earlier. Note complete healing of wound and excellent cosmetic result.

healing despite the establishment of adequate drainage. A satisfactory result was obtained only when all of the diseased tissues had been excised and the resulting defect closed by the approximation of well nourished, healthy tissues.

LUNG ABSCESS

The incidence of lung abscess was remarkably low in World War II (table 10) and the incidence of acute fulminating abscesses far lower than the incidence of chronic indolent abscess. During the entire war, only three acute lung abscesses required drainage at the Walter Reed General Hospital chest center. There were several explanations for this situation:

1. One of the chief etiologic factors in lung abscess, dental sepsis, was almost entirely eliminated in World War II by the excellent dental care provided for all soldiers in the Army.

2. The almost universal use of the sulfonamides, and later of penicillin, in pneumonia and other severe respiratory infections probably accounted for the absence of the fulminating infections formerly seen and also explained the presence of more chronic, less severe types.

3. Because of the effectiveness of penicillin, many patients with small abscesses, which were treated promptly, were probably cured in smaller hospitals and did not have to be referred to chest centers.

Chronic lung abscesses, nonetheless, furnished numerous problems. As early as October 1943, Major Blades reported to Colonel Carter that the thoracic surgeons at all centers complained that these patients were not being trans-

ferred to the centers early enough; most of them had been ill for 4 to 6 months when they were first seen.

In War Department Technical Bulletin (TB MED) 69 (*2*), 22 July 1944, directions were given to transfer all patients with lung abscesses to thoracic surgery centers if conservative treatment failed to produce prompt symptomatic improvement, accompanied by roentgenologic evidence of clearing of the surrounding pneumonia and progressive decrease in the size of the cavity. In view of the difficulties of management of chronic lung abscess, transfer was to be effected within 30 days of the patient's admission to the hospital unless the rate of healing clearly indicated that surgical treatment would not be required.

Management

As in other suppurative diseases, the response to penicillin of a patient with a lung abscess depended upon the process. A number of small, carefully supervised series showed that the only effect in abscesses of any severity was likely to be symptomatic improvement and that regression would occur as soon as therapy was discontinued. It could scarcely be expected that a pathologic process characterized by tissue destruction, necrosis, and gangrene would be improved by any antibiotic, even if the organisms present were sensitive to it and were of low virulence.

Even before the war, drainage of lung abscesses had fallen into disfavor because of the poor results. This operation decreased the sputum and reduced the fever, but it wrought no real improvement in a patient in whom an entire lobe had been destroyed and whose infection involved the interlobar fissures and had spread to adjacent lobes. It was only in very early cases, when the abscesses were well circumscribed and drainage was instituted promptly, that the results of conservative surgery were satisfactory.

Excisional surgery had begun to be popular before the war, as technical refinements and developments in anesthesia greatly reduced the surgical risks. It was the preferred method of treatment for chronic lung abscesses in the thoracic surgery centers in the Zone of Interior. The risk of lobectomy was somewhat greater than in bronchiectasis, but it was generally regarded as worth taking in view of the prospect of chronic invalidism which otherwise faced the patient, and, on the whole, the results were excellent.

EMPYEMA

When the sulfonamide drugs first became available, shortly before World War II, accumulated data promptly showed that the almost universal use of these agents in the treatment of pneumonia was resulting in a marked decrease in the postpneumonic variety of suppurative pleurisy. The local and systemic use of the various sulfonamide derivatives also showed, however, that once a purulent exudate had formed in the pleura, cure by chemotherapy was not possi-

ble: Toxic reactions prevented the use of sufficiently large doses by the systemic route to effect a cure, while local injections into the pleural cavity were equally ineffective, since the admixture with purulent fluid inhibited their antibacterial action.

Management

When penicillin became available, it seemed, at least theoretically, that it would be ideal for the management of postpneumonic empyema caused by micro-organisms susceptible to it. It has a strong antibacterial action when used systemically, and retains its potency in the presence of pus and blood. Its low toxicity permits the use of very large doses both locally and systemically with little risk of toxic or other side effects.

In spite of these favorable circumstances, the original high hopes were not fulfilled. When acute empyema was treated in the early stages by aspiration and injection of penicillin, there were numerous good results. This was not always true, however, even in acute cases, and it was seldom true in chronic cases, in which its prolonged use was an invitation to chronicity. There was no reason, for instance, for the 11 thoracenteses and 300 intramuscular injections of penicillin employed in one of the early cases over a 6-month period of hospitalization. There was never any justification, in fact, for the continuation of conservative treatment unless there was a progressive decrease in the size of the cavity accompanied by clearing of the purulent fluid.

In TB Med 69 (*2*), it was directed that surgical drainage must be employed when the pus in the empyema cavity was thick, since its presence predisposed to thickening and fixation of the pleura and the consequent development of chronic empyema. It was further directed that all patients with chronic empyema be transferred to a thoracic surgery center for treatment and disposition. An empyema was considered to be chronic when, at the end of 6 weeks after the original operation, the cavity measured 30 cc. or more.

The following policies of management finally become routine:

1. An injection of penicillin was given intrapleurally as soon as infected fluid was demonstrated in the cavity. Additional local therapy was then withheld until the organisms present were identified and it was determined that they were penicillin susceptible. Delay in local treatment was particularly emphasized when penicillin first became available and quantities were so limited that it could not be wasted.

2. If systemic penicillin had not been employed during the pneumonic stage of the disease, it was begun at once. The chief advantage of this route was that it put into the blood a bacteria-inhibiting substance which might prevent or control a spreading cellulitis or invasive infection. This was particularly important when the responsible organism was streptococcus or staphylococcus.

3. Three intrapleural injections of 50,000 units each, on alternate days, were usually sufficient. Before the injection, as much fluid as possible was removed by thoracentesis.

4. If exudate continued to form and became thicker, surgical drainage was established without further delay. Thick pus could not be evacuated satisfactorily by needle, and even sterile fluid was often so thick that thoracotomy was necessary for adequate drainage. Valuable as penicillin was as an adjunct to surgery, it did not permit the violation of fundamental surgical principles.

ACTINOMYCOSIS

Official statistics for actinomycosis show 207 admissions for this cause in the 1942–45 period, with 4 deaths and 24 separations for disability.

Particular interest was aroused in this disease at the Kennedy General Hospital chest center when the ray fungus was isolated in two patients under treatment for pulmonary suppuration. Thereafter, this organism was searched for routinely in all suppurative chest disease and was found with surprising frequency, as is evident in a report by Major Kay (*3*).

Between May and November 1945, *Actinomyces bovis* (*israeli*) was found in 109 of 240 patients under treatment for chronic bronchopulmonary infections. In no instance was it the only organism found. In a number of patients it appeared to predominate, but usually such other organisms as streptococci, staphylococci, spirochetes, fusiform bacilli, and other less common microorganisms were also identified. *Actinomyces* was found in the sputum in all 109 cases by direct examination and by culture, in specimens secured by bronchoscopy in 65 cases, in exudate aspirated from lung abscesses in 6 cases, and in drainage from sinus tracts in 2 patients with empyema secondary to pulmonary suppuration. The 65 patients from whom the organisms were cultured from bronchoscopic specimens included 37 with bronchiectasis and pneumonitis of varying degrees of severity, 8 with lung abscess, 5 with pulmonary suppuration, 5 with aspiration pneumonia, 2 with suppuration distal to obstructing carcinoma, and 8 with chronic bronchitis.

These findings at first caused considerable concern among medical officers whose previous experience with this condition had been limited to isolated cases. There was debate as to whether these cases should be considered as instances of bronchopulmonary actinomycosis or as instances of bronchopulmonary suppuration in which the ray fungus was present among other infecting organisms. As experience accumulated, it was evident that the clinical significance of *Actinomyces* was far less than had originally been feared. The clinical course and the response to surgery and chemotherapeutic measures did not seem to be influenced by its presence or absence; chronic pulmonary suppuration is a very chronic condition per se.

The precautions originally taken when *Actinomyces* was identified included increased dosages of the sulfonamides and penicillin before drainage operations and, in a number of instances, postponement of the indicated surgery, for fear of development of a chronic draining sinus and empyema after lobectomy. In no instance did this happen. The fungus was isolated in the

pleural fluid of one patient after pneumonectomy, but it promptly disappeared when intrapleural injections of penicillin and sulfadiazine were used. In other words, as time passed, it became evident that this fungus was of less significance in the clinical course, chronicity, and prognosis of pulmonary and pleural infections than the mechanical factors of bronchial occlusion or drainage, tissue destruction, fibrosis, and avascularity. Patients who presented these findings were just as resistant to conservative therapy as were patients who harbored *Actinomyces*.

Management

The response to treatment depended upon the chronicity and the severity of the infection. Penicillin and sulfadiazine, used in combination and in large doses, gave the best results, but it was important that they be continued well beyond clinical improvement and roentgenologic clearance; otherwise, recurrence was certain. The routine of treatment required the injection of 50,000 units of penicillin intramuscularly every 3 hours for 8 to 12 weeks or longer, and the maintenance of a sulfadiazine blood level of 10 mg. percent. It was thought that streptomycin might prove even more effective, but the evidence was inconclusive when the survey ended.

If cavitation was present, the routine just described was considerably less effective; the patients were improved symptomatically, and there was clearing of pneumonitis about the cavity, but the basic disease was not affected. Lobectomy was required in two cases in this series in which medical treatment failed and drainage was also unsatisfactory, and pneumonectomy was necessary in two similar cases. It was thought that one or the other of these procedures would also be necessary in other cases.

SPONTANEOUS PNEUMOTHORAX OF NONTUBERCULOUS ORIGIN

Spontaneous pneumothorax of nontuberculous origin was observed at all chest centers. Colonel Meade and Colonel Blades (*4*) analyzed the 18 cases jointly observed at the chest centers at Kennedy General Hospital and Walter Reed General Hospital. Eight of the pneumothoraces were recurrent, eleven were chronic, and all were cured by surgery. In 3 of the 18 cases, no etiologic factor could be determined. In the remaining cases, rupture of peripheral emphysematous blebs and bronchogenic cysts was the most frequent cause.

The policy was to perform open thoracotomy on any patient who did not respond promptly to simple aspiration of air or induction of a chemical pleuritis. The procedures employed included excision of blebs and cysts; closure of fistulas; division of isolated adhesions; lobectomy; and pulmonary decortication, which was necessary in five cases before satisfactory reexpansion of the lung was accomplished. Open operation was employed in all cases, so that the underlying cause could be dealt with and decortication performed if reexpansion was not satisfactory.

MALIGNANT NEOPLASMS

Incidence

Figures collected by the Medical Statistics Division, Office of The Surgeon General, for 1944 and 1945 (table 17) show a total of 205 primary admissions for malignant neoplasms of the thorax, of which 140 were in the lung and the bronchus. Another 45 admissions were recorded for secondary malignancy of the thoracic structures. No instances of malignant neoplasm of the trachea were recorded during this period. Though the total number of cases is small, a wide variety of histologic patterns is represented (table 18).

There were 141 deaths in the 205 primary malignant neoplasms, 83 of which occurred in the Zone of Interior (table 19). Men whose disease was discovered overseas were evacuated to the United States at once.

While the figures represent only the 1944–45 period, it is possible that both the 141 deaths and the 53 disability separations recorded for the 2 years include some patients admitted before 1944. As to the remaining 11 patients not included in the deaths and disability separations, it is highly probable that some died after separation from service.

Neoplasms of the lymphatic and hematopoietic tissue are not included in these tables, but some figures (based on 20 percent samples) are available. During the 1944–45 period, there were:

35 primary and 5 secondary admissions for neoplasms of the mediastinum, with 3 deaths and 10 disability separations.

5 primary admissions for neoplasms of the larynx, with 1 death and 1 disability separation.

Two deaths and three disability separations for this category of pulmonary neoplasms were also recorded during 1944–45.

Carcinoma of the Lung and the Esophagus

No special discussion of carcinoma of the lung during the war is called for. The manifestations were the same as in civilian life, most of the tumors being inoperable by the time the diagnosis was made. A number of highly malignant peripheral bronchogenic cancers gave no warning of their presence until metastases contraindicated even palliative surgery. Results were only slightly better in a smaller group of older patients whose tumors were centrally located and of the squamous cell type.

How discouraging the results of treatment were in carcinoma of the lung is evident in the 1945 report from Fitzsimons General Hospital: Of 10 bronchogenic carcinomas observed that year, 7 were inoperable when the diagnosis was made, and irradiation was completely ineffective; all 7 patients died promptly. Of the three who underwent pneumonectomy, one died of extensive metastases and one of pneumonia in the remaining lung 3 months after operation. The third patient in this group was still in the hospital undergoing irradiation when the report was made.

TABLE 17.—*Incidence of malignant neoplasms*[1] *of the respiratory system (by anatomic site) and of the esophagus, by area of admission, U.S. Army, 1944–45*

[Preliminary data based on 20 percent sample tabulations of individual medical records]

Area	Site of malignant neoplasm					
	Lung	Bronchus	Pleura	Mediastinum	Larynx	Esophagus
	NUMBER OF ADMISSIONS					
Continental United States	75	15	------	----------	25	5
Overseas:						
Europe	25	10	------	5	10	--------
Southwest Pacific	10	--------	------	----------	------	--------
Central and South Pacific	5	--------	5	5	5	--------
Latin America	------	--------	------	5	------	--------
Total overseas	40	10	5	15	15	--------
Total Army	115	25	5	15	40	5
	NUMBER OF SECONDARY CASES[2]					
Continental United States	10	--------	------	----------	------	--------
Overseas:						
Europe	10	--------	5	----------	5	--------
Mediterranean[3]	5	5	------	----------	------	--------
Central and South Pacific	5	--------	------	----------	------	--------
Total overseas	20	5	5	----------	5	--------
Total Army	30	5	5	----------	5	--------

[1] Neoplastic conditions of lymphoid and hematopoietic tissues are excluded.

[2] Ten secondary cases of malignant neoplasm of lung were reported among battle admissions—5 each in the European and the Central and South Pacific theaters; all other secondary cases were reported among disease admissions.

[3] Includes North Africa.

The outlook in malignant lesions of the esophagus was equally poor. In seven carcinomas observed at the Kennedy General Hospital chest center, three were found to be inoperable in exploration. Three were treated by resection with anastomosis, and the remaining patient underwent, respectively, total gastrectomy; transverse colectomy; and esophagojejunostomy, a procedure which almost implies a fatal outcome.

TABLE 18.—*Morbidity and mortality from malignant neoplasms*[1] *of the respiratory system (by anatomic site) and of the esophagus, by histologic type and type of case, U.S. Army, 1944–45*

[Preliminary data based on tabulations of individual medical records][2]

Anatomic site and histologic type	Admissions	Secondary cases	Deaths[3]	Disability separations[4]
Lung:				
Carcinoma	100	25	77	19
Liposarcoma	5	----------	1	----------
Osteogenic sarcoma	----------	5	----------	----------
Sarcoma, unspecified	----------	----------	1	----------
Endothelioma	----------	----------	1	----------
Malignant tumor, unspecified	10	----------	6	----------
Total	115	30	86	19
Bronchus:				
Carcinoma	20	5	26	4
Malignant tumor, unspecified	5	----------	1	----------
Total	25	5	27	4
Pleura:				
Carcinoma	5	----------	1	1
Endothelioma	----------	----------	----------	1
Mesothelioma	----------	5	----------	----------
Total	5	5	1	2
Mediastinum:				
Carcinoma	5	----------	5	1
Sarcoma, unspecified	5	----------	2	----------
Malignant tumor, unspecified	5	----------	9	6
Total	15	----------	16	7
Larynx:				
Carcinoma	30	5	3	15
Angiosarcoma	----------	----------	1	----------
Sarcoma, unspecified	----------	----------	----------	1
Chordoma	5	----------	----------	1
Malignant tumor, unspecified	5	----------	----------	----------
Total	40	5	4	17
Esophagus:				
Carcinoma	5	----------	7	4
Total	5	----------	7	4
Grand total	205	45	141	53

[1] Neoplastic conditions of lymphoid and hematopoietic tissues are excluded.
[2] Admissions and secondary cases are based on 20-percent samples; deaths and disability separations are based on complete files of the records.
[3] These are all deaths due to the conditions indicated which occurred during 1944–45.
[4] These are all cases separated from the service during 1944–45 because of disability from the conditions indicated.

TABLE 19.—*Deaths due to malignant neoplasms*[1] *of the respiratory system (by anatomic site) and of the esophagus, by area of admission, U.S. Army, 1944–45*[2]

[Preliminary data based on tabulations of individual medical records]

Area	Malignant neoplasms in—					
	Respiratory system, by anatomic site					Esophagus
	Lung	Bronchus	Pleura	Mediastinum	Larynx	
Continental United States	55	14	------	7	3	4
Overseas:						
Europe	12	6	------	2	1	1
Mediterranean [3]	8	1	------	1	------	1
Middle East	------	1	------	------	------	------
China-Burma-India	1	1	------	------	------	------
Southwest Pacific	5	------	------	2	------	------
Central and South Pacific	3	1	1	3	------	1
North America [4]	1	1	------	------	------	------
Latin America	------	2	------	1	------	------
Total overseas	[5] 31	13	1	9	1	3
Total Army	86	27	1	16	4	7

[1] Neoplastic conditions of lymphoid and hematopoietic tissues are excluded.
[2] These are all deaths due to the conditions indicated which occurred during 1944–45.
[3] Includes North Africa.
[4] Includes Alaska and Iceland.
[5] Includes one death among admissions on transports.

Tumors of the Mediastinum

During the 3-year period of their activity, 109 patients with mediastinal tumors were operated on at the five thoracic centers in the Zone of Interior. The figures collected by Colonel Blades (*5*) include only the cases in which the chest was explored because of symptoms or because of the discovery of a mediastinal mass on routine roentgenologic examination, which was the primary means of diagnosis in 94 of the 109 cases.

Five of the masses proved to be aneurysms, not neoplasms. Of the 104 true tumors, 15 were malignant and 89 were benign.

The malignant group included six teratomas, two thymomas, two lymphoblastomas, and one neurosarcoma. It also included four instances of Hodgkin's disease, in three of which the diagnosis was not realized until histologic examination of the specimen. In one case, the tumor had invaded the upper lobe of the lung, and lobectomy was necessary for its removal. Surgical intervention would not have been undertaken deliberately in any of these cases if the true nature of the tumor had been established before operation. Short-term observation, however, showed that the patients had not been harmed by removal

of the visible tumors, and there was some evidence that they might have been benefited.

Exclusive of the 4 instances of Hodgkin's disease and the 5 aneurysms just mentioned, the essential data in the remaining 100 cases were as follows:

Bronchogenic cysts.—There were 23 bronchogenic cysts in this series, a surprisingly large number considering the fact that up to 1945, according to Laipply (*6*), only 35 had been recorded.

Only 2 of the 23 patients had clinical manifestations. In the remainder, the mass was found on roentgenologic examination. Even with detailed studies, the true nature of the masses was difficult to establish. On the frontal projection, they suggested either teratoid tumors or primary nerve tumors. On the lateral view, the shadow was not so distinct as in teratoid tumors, and the extreme posterior position characteristic of most primary nerve tumors was not evident. Since most bronchogenic cysts are attached to the trachea (most often near the tracheal bifurcation in the superior mediastinum), the mass moved during swallowing, as could be demonstrated by fluoroscopic examination, which was of some diagnostic assistance. A patent lumen communicating with the trachea or a bronchus was not demonstrable in any case.

There were two sound reasons for advising the surgical removal of bronchogenic cysts even if they were asymptomatic:

1. There was no reliable method, except surgical exploration, for determining the true nature of the tumor. Many neoplasms of the mediastinum with grave malignant potentialities resemble bronchogenic cysts on roentgenologic examination. Moreover, since bronchogenic lesions are considered as cell rests, there is no assurance that malignant changes will not occur in them.

2. Bronchogenic cysts may become infected. If they do, operative interference is necessary, and technical difficulties at this time may be considerable. Also, cysts which are presently asymptomatic may increase in size and produce later pressure and other symptoms.

Teratoid tumors.—Twenty of the tumors in this series were teratoid, to use the inclusive nomenclature suggested by Harrington (*7*). Fourteen were benign and were removed without difficulty. Advanced changes were evident in the six malignant growths. Only surgical extirpation can be considered for these tumors, because of the risk of malignant degeneration.

Up to 1945, close to 250 teratoid tumors had been reported in the medical literature (*6*), and they are the most common lesions of the anterior mediastinum. In the collected cases, only three were in other locations. The number observed in the chest centers during World War II would undoubtedly have been larger except that these tumors produce sharp shadows and are so easily detected by roentgenogram that most men who harbored them were probably identified at the preinduction examination and were rejected for service.

Neurogenic tumors.—The 29 benign primary nerve tumors of the mediastinum observed in this series included chiefly neurofibromas, ganglioneuromas, and sympathicoblastomas. Up to 1944, 105 of these tumors had been collected

by Kent and his associates (*8*), all but 2 of which were located posteriorly. In their series, 37 percent of the tumors had undergone malignant change, which makes clear why surgical excision is the correct treatment as soon as the tumor becomes evident.

One patient with a neurogenic sarcoma was explored, but invasion of the surrounding structures precluded its removal. All the other tumors were excised.

Pericardial cysts.—The 10 pericardial cysts in the series were all discovered on routine roentgenologic examination. Except for their characteristically anterior location, there is nothing to differentiate these cysts from other mediastinal tumors, and surgical excision is the only way to establish their character.

Thymomas.—Four of the six patients with thymomas, two of which were malignant, had no symptoms referable to the mass. In one case, in which the patient had advanced myasthenia gravis, it was impossible to remove the malignant mass completely.

Lipomas.—Only 4 lipomas were encountered, which is not surprising, since less than 40 mediastinal tumors of this type could be collected by Watson and Urban (*9*) in 1944.

Other tumors.—Other mediastinal tumors in this series included one fibroma, which was probably a neurofibroma; one thyroid adenoma; one cyst arising from the esophagus; one osteochondroma; one Boeck's sarcoid, diagnosed by biopsy of tissue at the hilus; and two tuberculomas.

Comment.—There was not complete agreement among the surgeons at the chest centers as to the best exposure for mediastinal tumors. Some routinely employed a posterolateral exposure; others preferred an anterior approach if the location of the tumor made it logical. The technique employed usually reflected the early training which the surgeon had received. On one point there was general agreement, that if difficulties were anticipated, a lateral or posterolateral incision should be used.

Before World War II, tumors of the mediastinum were frequently treated by irradiation, surgery being resorted to only if satisfactory results were not accomplished. This was never a safe or a desirable plan. As has been pointed out several times in this brief analysis of the 109 mediastinal masses treated at the chest centers in the Zone of Interior during World War II, it is not possible, in most instances, to determine the true character of a mediastinal tumor without direct inspection at operation. If operation is delayed until symptoms and signs become apparent, the chance for successful extirpation will frequently have been lost.

The reasoning behind the use of irradiation in preference to exploration was the risk originally attendant upon exploratory thoracotomy. This risk ceased to exist when refinements in surgical and anesthetic techniques made exploration of the chest safe. Risks were negligible in the chest centers during

World War II. Errors in diagnosis occasionally occurred, and a few tumors were operated on which might have responded to irradiation, but the danger to the patients was slight compared to the harmful potentialities of prolonged and ineffective irradiation. Irradiation will not reduce the size, or halt the malignant degeneration, of these tumors unless they are of lymphatic origin, and surgery is more dangerous and more difficult after prolonged use of X-rays.

The results in this series justify the management of mediastinal tumors by prompt exploration of the chest. There were no deaths that could be attributed to the operation and no postoperative complications in the cases in which only exploration and biopsy were performed. Suppurative pleuritis developed in three cases in which a tumor was removed, but adequate drainage was followed by prompt healing. In one of these cases, it had been necessary to remove an infected right middle lobe that had been eroded by a teratoma.

LESIONS OF THE ESOPHAGUS

In addition to the seven malignant tumors of the esophagus treated at Kennedy General Hospital, Major Kay's (*10*) survey of esophageal lesions at that center included:

2 benign new growths (neurofibroma and leiomyoma).

5 cysts (2 dermoid, 1 bronchogenic).

9 diverticula (4 traction, 3 pulsion, 1 epiphrenic).

1 varix (too extensive for treatment).

9 hiatal hernias (5 treated surgically).

4 paraesophageal hernias (1 treated surgically).

20 cardiospasms (11 treated surgically).

11 obstructions due to extrinsic tumors, cysts, aneurysms and tuberculous nodes (all treated by measures directed to the extrinsic lesion).

8 congenitally short esophagi (3 associated with stricture and 4 with ulcer).

18 strictures (11 due to ingestion of "sabotaged alcoholic beverages consumed accidentally overseas," and 3 to attempts at suicide).

24 traumatic injuries and war wounds (fistulas, abscesses, strictures, retained foreign bodies).

Management of all of these lesions followed the policies general in civilian practice. There was only 1 death in the 42 major operations performed.

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CHAPTER XI

Long-Term (1943–61) Followup Studies in Combat-Incurred Thoracic Wounds

Lyman A. Brewer III, M.D.

Followup information is as notably deficient concerning casualties with combat-incurred wounds of the chest as it is concerning most other casualties. There are almost no studies of this kind in the medicomilitary literature, which is extremely unfortunate, for it makes it impossible to determine the true end results of any given plan of management.

Up to March 1944, chest wounds sustained in the Mediterranean (formerly North African) Theater of Operations, U.S. Army, in World War II were treated according to the personal policies of the surgeon who handled the particular patient. After this date, thoracic casualties were treated by a specific regimen that differed, in many respects, from the policies employed earlier.

The investigation reported in this chapter was undertaken in an attempt to trace the postwar course of a group of casualties who had sustained chest injuries in the Mediterranean theater and who had all been treated (1) in forward hospitals, (2) under the direction of a single surgeon and his assistants, (3) by the specific regimen just mentioned. This group of patients was followed into the hospitals of the communications zone and the Zone of Interior, and some of them were followed up for varying periods of time, up to February 1961, after their separation from service.

BACKGROUND OF STUDY

In the summer of 1943, during the Sicilian campaign, studies at the thoracic surgery center at Bizerte, North Africa, on casualties returning from forward areas revealed a high mortality rate and a considerable morbidity among the group treated by thoracotomy at initial wound surgery. The impression arose that this operation was being performed on unnecessary indications in forward hospitals and that its promiscuous use was having an adverse effect on the results of chest injuries.

On the basis of these impressions, Col. Edward D. Churchill, MC, Consultant in Surgery to the theater surgeon, detached Capt. (later Maj.) Lyman A. Brewer III, MC, from his duties at the Bizerte chest center and assigned him to the forward hospitals supporting the landings at Salerno in September

746-941v—65——31

1943. His mission was to study the problems of forward surgery in thoracic injuries and to continue the investigation as the troops advanced into Italy.

Two facts promptly became apparent to Captain Brewer:

1. Thoracotomies were indeed being performed unnecessarily in forward hospitals as part of initial wound surgery.

2. In spite of this fact, the indications for thoracotomy in forward hospitals could be very sharply defined.

At a conference of thoracic surgeons called, and presided over, by Colonel Churchill in March 1944, at Marcianese (vol. I), the results of Captain Brewer's investigations were reported. At this meeting, the indications for primary thoracotomy in forward hospitals were defined, and the so-called limited approach to this operation thereafter became the prescribed policy in the Mediterranean theater.

This followup study had its genesis during the war, when Captain Brewer took upon himself the task of keeping duplicate individual records for all casualties with thoracic injuries treated by him as head of Thoracic Surgical Team No. 4, 2d Auxiliary Surgical Group. The team consisted of Captain Brewer; Capt. Charles A. Schiff, MC; Capt. Werner F. A. Hoeflich, MC; and 1st Lt. Catherine V. Elliott, ANC.

Team No. 4 served first with the Fifth U.S. Army in Italy and then with the Seventh U.S. Army in France, Germany, and Austria. This army originated in the Mediterranean theater and remained under its operational control for the landings in southern France in August 1944 and during the first part of the campaign in France. In December 1944, it passed to the logistic control of the European theater.

The team served in forward hospitals during the landings at Salerno in September 1943 and the campaign in Italy, the landings at Saint-Raphaël and the campaign in southern France, and then during the campaigns in Germany and Austria until V–E Day in May 1945. It was variously attached to the 94th Evacuation Hospital (Salerno to Cassino), the 11th Field Hospital (Cassino), the 11th Evacuation Hospital (Anzio to Civitavecchia), the 11th Field Hospital (from the D-day landings at Saint-Raphaël into eastern France), the 66th Field Hospital (Vosges Mountains), and the 80th Field Hospital (Germany and Austria).

The casualties were thus encountered, and the surgeons worked, under a wide variety of conditions of climate and terrain, in Italy, France, Germany, and Austria, at all seasons, and from beachheads to mountains.

MATERIALS AND METHODS

Although Major Brewer and his team had personally treated more than 1,000 casualties with combat-incurred wounds, only 822 had wounds of the chest, and only 372 of these were treated in forward hospitals. Of the 210 patients

whose histories were reviewed when this analysis was undertaken, only 167 had sufficiently detailed records to make followup investigation of any real value.

There are numerous problems connected with such an investigation. The tracking down of a large number of former soldiers for varying periods of time (from 3 to 17 years) after the termination of hostilities and their return to civilian life was not simple. It was impossible, in fact, to follow the majority because of the general movement of the population that now seems part of the way of life in the United States. Had all of these men reported for further treatment to VA (Veterans' Administration) clinics and hospitals, there would have been no problem. Most of them did not. As will be pointed out later, their failure to seek medical advice is probably a reflection of the fact that most of them did not think that they needed it.

The Veterans' Administration, however, is the most obvious source of help in an undertaking of this kind, and with few exceptions, the men followed up in this series after separation from service are those who reported to VA hospitals and clinics, either because they were disturbed over their status or because they were actually in need of treatment.

Whatever success was achieved in this investigation is attributed to three agencies:

The project was initiated with the complete cooperation, and had the assistance throughout, of The Historical Unit, U.S. Army Medical Service, a class II activity of The Surgeon General, Department of the Army, under whose direction the volumes in this historical series are being prepared.

It also had the complete cooperation of the Veterans' Administration and of the Federal Records Center, General Services Administration, St. Louis, Mo. (formerly the Army Records Center). Through the painstaking efforts of the personnel of these two agencies, records were collected from numerous sources and were forwarded to the study center in the VA Regional Office in Los Angeles, Calif.[1]

In some instances, these records were well over an inch thick. A great deal of the material included in them consisted of correspondence concerning disability claims, pensions, and similar matters, but when it was winnowed, it contained sufficient medical evidence to make good followup studies possible in 167 patients.

In a number of cases, additional followup material was obtained by direct correspondence with the veterans themselves. This method made it possible to obtain firsthand, personal reports of their current status and also to secure current roentgenograms.

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[1] It should be added that this truly unique investigation was the concept of Dr. Lyman A. Brewer III, and that it was through his vigorous personal efforts that it was brought to a successful conclusion.—F. B. B.

THORACIC WOUND STUDY, WORLD WAR II.

Return to: Lyman A. Brewer III M.D.
2010 Wilshire Blvd.
Los Angeles 57, Calif.

Name________________________________Age:________
Rank____________________________Unit:____________________
Serial No.______________Date W.__________USA ☐ USN ☐ USAF ☐ 1. Other ☐ POW ☐
FORWARD HOSP.______________________Location____________________

Date Op.________________ 2 Block ☐ 5 TSC ☐ 8 Tr. Thor. ☐ 11 Hem. Thor. ☐ Other ☐
Type________________ 3 Debrd. ☐ 6 Pl. Drain ☐ 9 Med. Thor. ☐ 12 Other ☐
4 Br. Aspr. ☐ 7 Thor. Abd. ☐ 10 Card. V. Thor. ☐

CLASSIFICATION OF WOUND:
13 Chest Wall ☐ 18 F. B. Pl. ☐ 23 L. Hem. ☐ 28 Diaph. ☐ 33 Spleen ☐ 38 Head ☐
14 Ribs ☐ 19 F. B. Lung ☐ 24 Tr. Br. ☐ 29 Stm. ☐ 34 Renal ☐ 39 Neck ☐
15 Pnx. ☐ 20 F. B. Med. ☐ 25 Esoph. ☐ 30 Sm. Int. ☐ 35 Pancr. ☐ 40 Arms ☐
16 Hemnx. ☐ 21 F. B. Ht. ☐ 26 Heart ☐ 31 Lg. Int. ☐ 36 Vascular ☐ 41 Pelvis ☐
17 F. B. C. W. ☐ 22 Lung Lac. ☐ 27 Med. ☐ 32 Liver ☐ 37 Retpr. ☐ 42 Legs ☐

COMPLICATIONS:
43 Blast ☐ 46 Wet Lung ☐ 49 W. Infect. ☐ 52 Lung Abc. ☐ 55 Med. Abd. ☐
44 Shock ☐ 47 Hemothor. ☐ 50 Empyema ☐ 53 Br. Fistula ☐ 56 Abdom. ☐
45 Coma ☐ 48 Cord. Paral. ☐ 51 Pneumonitis ☐ 54 Esoph. Fistula ☐ 57 Other ☐

DISPOSITION:
58 Died ☐ 59 Duty ☐ Date: 60 Evac. ☐
Date: Cause of Death: Date:

FOLLOW-UP: NAME____
ZONE COM. HOSP.__________________Location:______________Adm. Date________

Further Surgery:
61 C. W. Drain ☐ 63 F. B. Rem. ☐ Site__________66 Other ☐ Type____________
62 Emp. Drain ☐ 64 Decort. ☐ 65 Abd. Op. ☐ Type____________

Complications:
67 W. Infection ☐ 69 Lung Inf. ☐ 71 Abd ☐ Type____________
68 Empyema ☐ 70 Clot Hemx. ☐ 72 Other ☐ Type____________

Disposition:
73 Died ☐ Cause of Death:______________________________
74 Duty ☐ 75 Z. I. ☐ Date:______________________________

ZONE INT. HOSP.__________________Location______________Adm. Date________

Further Surgery: 76 C. W. Drain ☐ 81 F. B. Rem. ☐ Type____________
77 Emp. Drain ☐ 79 Lung Resec. ☐ 82 Abd. Op. ☐ Type____________
78 Decort ☐ 80 Thorpl. ☐ 83 Other ☐

Complications: 84 W. Inf. ☐ 86 Lung Inf. ☐ 88 Br. Fist. ☐ 90 Med. Abs. ☐ 92 Other ☐
85 Empyema ☐ 87 Lung Abc. ☐ 89 Esoph Fist. ☐ 91 Abd. ☐

Disposition: 93 Died ☐ Date:__________ Cause of Death:____________________
94 Duty ☐ Date:__________ 95 Disability ☐ 96 Chest Cause____________
REMARKS:______________Date:__________ 97 Other ☐ Rating % ☐

FIGURE 195.—Punchcard designed to secure data in long-term followup of veterans with combat-incurred wounds of chest. Top, front. Bottom, back.

BASIC DATA

The data were collected on punchcards especially made up for the project (fig. 195).

The age range of the 167 casualties was from 18 to 39 years. Of this number, 16 were in the 18- to 19-year group, 118 in the 20- to 29-year group, and the remainder (33) in the 30- to 39-year group.

In 131 instances, the wounding agents were shell fragments and in 36, gunshot.

Both in age distribution and in wounding agents, therefore, the patients in this series are representative of all types of combat casualties in World War II.

THERAPEUTIC CLASSIFICATION

The 167 patients were studied in two groups, according to their management in forward hospitals, as follows:

1. In 86 cases, wound debridement was carried out in forward hospitals, but thoracotomy was not performed.

2. In the remaining 81 cases, in 25 of which the wound was thoracoabdominal, either thoracotomy or a combined thoracic and abdominal operation was carried out.

This classification is based on the point, already emphasized, that careful definition of the indications for, and contraindications to, thoracotomy in forward hospitals was one of the major contributions made by thoracic surgeons who treated chest wounds in the Mediterranean theater in World War II. One of the most important objectives of this study was to determine whether any casualty in the group in which thoracotomy was omitted had died later from complications or had suffered delayed morbidity referable to his wound. Only a long-term followup could settle this point.

The components of both resuscitation and initial wound surgery have been described in detail in the first volume of this thoracic surgery) subseries.

INITIAL WOUND SURGERY

In the group of patients in whom thoracotomy was not considered necessary at initial wound surgery, the penetrating wound produced by the missile was of such limited dimensions that the wound did not suck (blow) originally or after adequate debridement. In this type of wound, as in all others, important considerations, in addition to the size of the missile, included its angle of penetration, its velocity, the damage to the bony cage, and the thickness of the original protecting musculature. The location of the wound was obviously a matter of great importance. A wound up to 2 cm. in diameter, if it was located in the interior thoracic cage, might result in a traumatic thoracotomy, while a wound up to 14 cm. in diameter, if it was located in the scapular region pos-

teriorly, might not result in traumatic thoracotomy, even after extensive debridement. It was also generally true that smaller external wounds were likely to produce less damage within the chest than would larger wounds. In 3 of the 86 cases in which primary thoracotomy was omitted, blast injuries were associated with powder and dirt burns of the chest, but neither the injury nor the possibility of internal damage was considered an indication for immediate thoracotomy.

In the remaining 81 cases, the initial wound was so extensive that it constituted, in itself, a traumatic thoracotomy; or the necessary debridement was so extensive as to produce a traumatic thoracotomy; or intrathoracic or intra-abdominal damage required entrance into these cavities to control hemorrhage or repair damaged organs.

The indication for thoracotomy in 56 of these 81 cases was serious damage to the chest wall or the intrathoracic contents. In six cases in this group, the diaphragm was lacerated, but the abdomen was not penetrated. In three other cases, the diaphragm was lacerated and the liver was penetrated by small foreign bodies, 2 mm. in diameter in each instance. In none of the three cases was the injury sufficient to cause either hemorrhage or extravasation of bile, and thoracolaparotomy did not prove necessary at the base section later. Small foreign bodies in the liver are usually well tolerated. Had the injuries been more serious, exploration of the abdomen would have been necessary.

In the remaining 25 cases, the wounds were thoracoabdominal, and intra-abdominal procedures were necessary. The number of casualties in this group would have been larger except for the fact that patients with abdominal injuries associated with chest injuries were considered within the province of general surgeons. These casualties were always classified as nontransportable at triage, and they were treated in forward installations, very often by general rather than thoracic surgeons.

Since thoracotomy was done in over half of the 167 cases in this series, the emphasis on limited thoracotomy may seem somewhat misplaced. There are at least two valid reasons for the high proportion:

1. All the patients who were treated by primary thoracotomy were first-priority, nontransportable casualties. The data (tables 20–23) show that both intrathoracic and extrathoracic damage were frequently extremely severe.

2. The concentration of so many serious injuries in such a small series is explained by the fact that frequently in forward areas in which there were few or no thoracic surgeons, thoracic casualties were referred to Thoracic Surgical Team No. 4, which served as a sort of unofficial forward thoracic surgery center.

Another index of the severity of the injuries in this series is the length of hospitalization in forward hospitals. The 86 patients in whom primary thoracotomy was not done were held from 7 to 14 days, on the average, while the 81 who required thoracotomy were held, on the average, from 4 to 7 days longer. An occasional patient in both groups had to be evacuated before the optimum time because of the tactical situation.

TABLE 20.—*Thoracic damage in 167 followed-up thoracic casualties according to surgical procedures in forward hospitals*

Thoracic damage	Surgical procedure			Total
	Thoracotomy		Thoracoabdominal surgery	
	Yes	No		
Chest wall:				
Soft tissue	56	86	25	167
Bony cage	69	23	19	111
Persistent pneumothorax	10	13	5	28
Persistent hemothorax	45	29	17	91
Foreign bodies:				
Chest wall	8	18	9	35
Pleura	14	4	3	21
Lung	18	15	3	36
Mediastinum	6	1	3	10
Pulmonary laceration	38	12	11	61
Pulmonary hematoma	27	53	9	89
Mediastinal injury	7	4	2	13
Diaphragmatic injury	9	1	25	35

TABLE 21.—*Associated injuries in 167 followed-up thoracic casualties according to surgical procedure*

Region	Surgical procedure			Total
	Thoracotomy		Thoraco-abdominal surgery	
	Yes	No		
Head	5	5	1	11
Neck	5	9	1	15
Pelvis	7	6	3	16
Extremities:				
Upper	23	22	7	52
Lower	12	21	5	38
Spine	1	---	1	2
Blast	9	6	6	21

TABLE 22.—*Intra-abdominal damage in 81 followed-up thoracic casualties according to surgical procedure*

Viscera and structures injured	Surgical procedure		Total
	Thoracotomy	Thoracoabdominal surgery	
Diaphragm	10	21	31
Stomach	3	4	7
Small intestine		5	5
Large intestine		5	5
Liver	2	11	13
Spleen		6	6
Kidney		5	5
Pancreas		1	1
Vessels	3	3	6
Retroperitoneum		4	4

TABLE 23.—*Complications in forward and fixed hospitals in 167 followed-up thoracic casualties according to surgical procedures in forward hospitals*

Complications	Surgical procedures in forward hospitals				Surgical procedures in fixed hospitals				Grand total
	Thoracotomy		Thoraco-abdominal surgery	Total	Thoracotomy		Thoraco-abdominal surgery	Total	
	Yes	No			Yes	No			
Shock [1]	8		4	12					12
Coma	1		1	2					2
Wet lung	37	22	6	65					65
Hemothorax	18	5	3	26					26
Wound infection					5	2	3	10	10
Empyema	1		2	3	4	3	2	9	12
Pneumonitis	1	2	2	5					5
Lung abscess	2			2					2
Chronic hemothorax	2	4	5	11					11
Bronchial fistula	2			2					2
Abdominal [2]			1	1	4		6	10	11
Other [3]	5	7	4	16	1	3	3	7	23

[1] Severe only.
[2] Subphrenic and peritoneal abscesses, et cetera.
[3] Hepatitis, amputations, toxic psychoses, et cetera.

SUBSEQUENT SURGERY

In oversea hospitals.—By the time the Italian campaign began, excellent facilities had been provided in the thoracic surgery centers in base sections of the North African theater for handling thoracic and thoracoabdominal casualties. The principles of treatment were becoming standardized. Well-trained and experienced personnel were available. Also, it was possible to keep the patients in these hospitals, when necessary, for periods up to 150 days.

Delayed primary wound closure, with or without redebridement, accounted for the largest number of operations (59) necessary in base section hospitals (table 24). No undue morbidity followed the removal of retained foreign bodies in 13 cases; in fact, the patients were then in much better condition to withstand the procedure than they were immediately after wounding.

Most of the drainage operations for infections of the chest wall and for empyema (seven each) were required because of the extent of the original wound and the serious contamination that had occurred.

Seven decortications were carried out for empyema and two for organizing hemothorax. Most of the patients in the empyema group had been treated only by debridement and thoracentesis in forward hospitals.

Colostomies were closed twice, both in patients in particularly good condition. It was always desirable to perform this operation overseas if it could be done.

As these data show, most surgery in base section hospitals, aside from delayed primary wound closure, was necessary for infections of the chest wall and pleural cavity. Persistent pneumonitis was not seen in any of these patients.

TABLE 24.—*Surgery required in fixed hospitals according to surgery performed in forward hospitals*

Surgery in fixed hospitals	Previous surgery in forward hospitals			Total
	Thoracotomy		Thoraco-laparotomy	
	Yes	No		
Drainage of chest wall	2	3	2	7
Drainage for empyema	5	1	1	7
Removal of foreign body	5	7	1	13
Decortication	4	4	1	9
Abdominal surgery	2	--------	4	6
Delayed primary wound closure	26	31	2	59
Other	8	12	6	26

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In Zone of Interior hospitals.—Only a small amount of surgery was necessary in these casualties in Zone of Interior chest centers:

Two patients required drainage for empyema 5 and 6 months, respectively, after wounding. One had had a traumatic thoracotomy and the other a thoracoabdominal wound.

In three instances, removal of foreign bodies was necessary. In the first case, the missile was removed from the lung of a patient who had had debridement without thoracotomy in a field hospital. In the second, the missile was removed from the abdomen when a colostomy was closed. In the third case, the object was removed from the liver.

The only other thoracic surgery required was excision of an arteriovenous fistula involving the internal mammary artery.

Chest pain and dyspnea were the principal complaints of casualties who were not returned to duty from Zone of Interior chest centers. In practically all of these cases, as will be pointed out later (p. 523), physical and roentgenologic examinations showed excellent lung expansion and minimal pleural reaction.

MORTALITY AND DISPOSITION

Deaths.—Four deaths occurred in base section hospitals, all in casualties with multiple wounds, all of whom had been serious problems from the moment they were carried into the shock tent of the field hospital until they died in a fixed hospital in the base. Three had thoracoabdominal wounds; hepatic infection and jaundice were factors in each fatality, and one patient also had peritonitis. The remaining casualty had a traumatic thoracotomy and a spinal cord injury with paraplegia. He died of pulmonary complications and secondary hemorrhage soon after evacuation from the field hospital.

Disposition.—Two casualties, both of whom had small wounds limited to the chest, were discharged from forward hospitals directly to their units.

In view of the multiplicity and severity of the wounds sustained by most of the remaining patients in this series, it is surprising to learn that about half of them could be returned to duty in the theater, most to limited duty but a few to active frontline combat. The larger number of casualties returned to duty, 50, were in the group in which primary thoracotomy was not necessary, but 38 patients who required thoracotomy and 5 who required thoracoabdominal surgery were also returned to duty. This was, of course, a sound policy in an oversea theater, in that it conserved manpower in the theater and reduced the need for replacement from the Zone of Interior. One reason that it was possible was that the holding time in base section hospitals, sometimes up to 5 months, was sufficient for small wounds to close by secondary intention,[2] for wounds closed by delayed primary suture to heal solidly, for pleural effusions to be absorbed, and for hematomas of the lung to resolve.

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[2] Two kinds of wounds were allowed to heal by secondary intention: (1) those in which infection was just enough of a possibility to make surgeons in the base hospitals hesitant to perform delayed primary closure, and (2) large clean wounds which for one reason or another were not suitable for delayed primary closure.

In the Zone of Interior, only 17 patients were returned to duty, most of them to limited duty. The group was about equally divided between those who had undergone primary thoracotomy and those who had not. The number was necessarily small, in view of the policy in the Mediterranean theater of not evacuating casualties to the Zone of Interior, unless there was a shortage of beds, until it was reasonably clear that they could not return to duty in the oversea theater.

When the group of patients returned to duty overseas is added to the group returned to duty in the Zone of Interior, it is seen that more than two-thirds (112) of the 163 patients who survived surgery in forward and base hospitals could be returned to some form of useful army service. Had the war continued and this same trend continued, there would have been an enormous saving in manpower. As it was, it is impossible to estimate the morale factor inherent in the return to duty of such a large number of seriously wounded men.

The postwar status of these casualties will be discussed later.

The case histories which follow have been selected from the histories of the 167 patients followed up after forward surgery to illustrate special conditions and complications and the methods of treatment employed for them. They are deliberately presented in some detail.

WOUNDS OF THE CHEST WALL

Although the chest wall was, of course, involved in all penetrating wounds of the chest, in 22 cases in this series, these wounds were small. They were sometimes associated with serious intrathoracic problems, but in all cases, the wounds themselves were readily managed by simple debridement.

In the remaining 145 cases, trauma to muscle masses and the bony cage was extensive enough to create challenging clinical problems. Foreign bodies were present in 35 cases, and there were 88 sucking wounds and 4 thoracoabdominal wounds in the series. The bony case was involved 101 times, the ribs 77 times, the scapula 13 times, the sternum 6 times, and the spine 5 times.

Wound infection was not a serious problem in any field hospital, but in 10 of these 145 cases, drainage of the wound was necessary for this reason in base section hospitals. In all 10 cases, the relation between the development of infection and the time at which debridement was performed seemed clear cut; in a few cases, initial wound surgery had been delayed up to 72 hours. Empyema developed in 9 cases at the base section and in 2 others in the Zone of Interior, but in only 2 of these 11 cases did a severe wound infection exist.

Case 1

Management overseas.—This 31-year-old infantryman was wounded in the chest at 1130 hours on 14 October 1944, near Hupelmont, France. Three hours later, he received a plasma transfusion of 1,000 cc. in a battalion aid station, where the sucking wound of the anterior chest wall was closed by skin

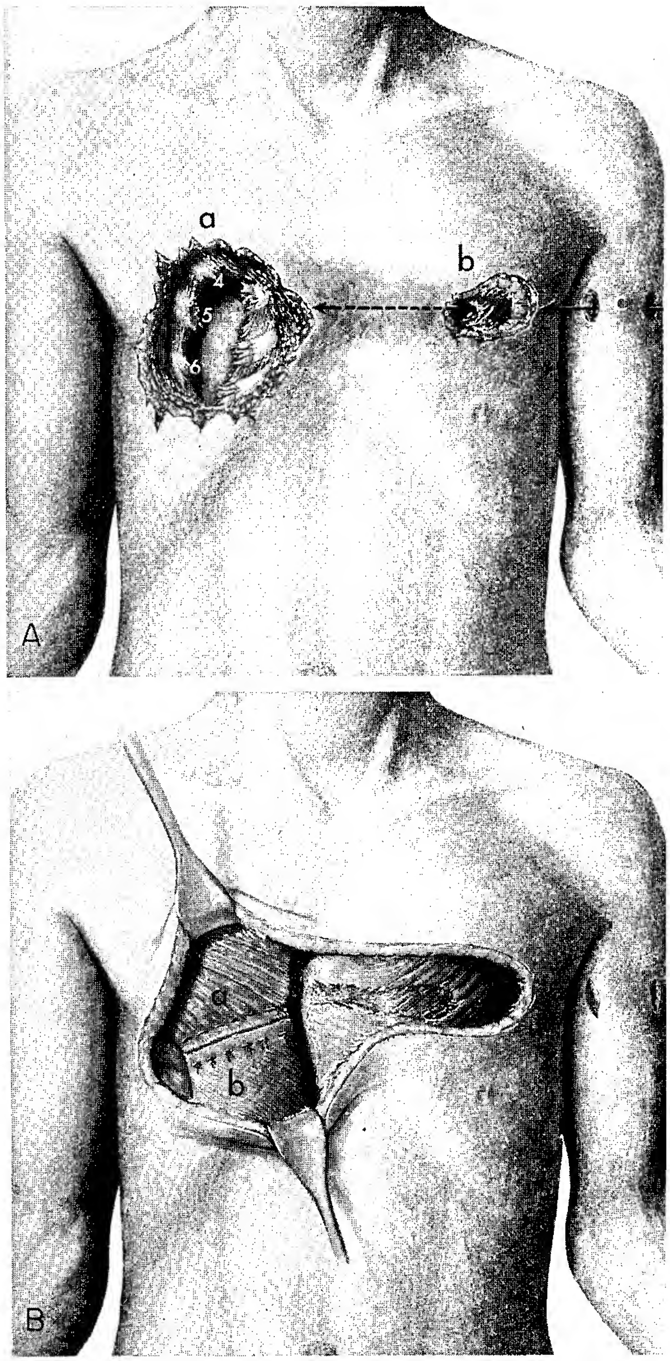

FIGURE 196. (*See opposite page for legend.*)

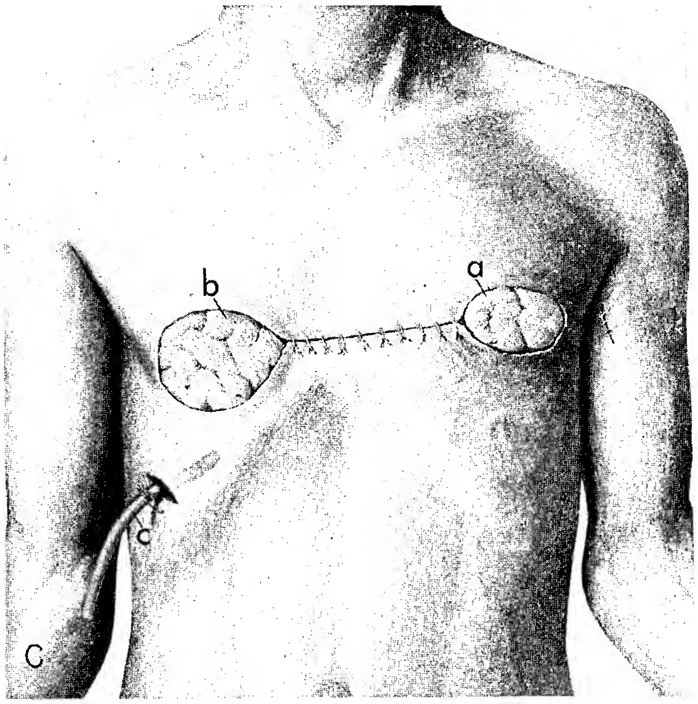

FIGURE 196 (case 1).—Schematic showing of large defects of chest wall. A. Wound: Large sucking wound of exit in right anterior chest wall, with destruction of portions of fourth, fifth, and sixth ribs and the corresponding costal cartilages (a), wound of entrance in left chest (b), and through-and-through wound of left upper arm (c). B. Closure of large chest wall defect by suture of mobilized pectoralis major (a) and rectus abdominis (b). C. Closure of central portion of wound with wounds of entrance (a) and exit (b) left open down to fascia, and closed drainage tube in situ (c).

sutures and a sulfonamide powder was placed in it. He was given morphine gr. $\frac{1}{4}$ and, because of wet breathing, atropine gr. $\frac{1}{50}$.

When he was received at the 11th Field Hospital at Eloyes, France, at 1545 hours, he was dyspneic and cyanotic, and his breathing was still wet. A large wound in the anterior chest wall (fig. 196A) extended from the anterior axillary line on the right at the sixth interspace across to the fourth rib in the anterior axillary line on the left. Breath sounds were heard bilaterally distant on the right, and there were numerous rales and rhonchi throughout both lung fields.

The resuscitative regimen included oxygen by nasal catheter; penicillin intramuscularly; thoracentesis, with removal of 300 cc. of bloody serous mucus from the right chest; intercostal nerve block, including the fifth through the eighth nerves; and catheter aspiration, which produced bloody serous mucus.

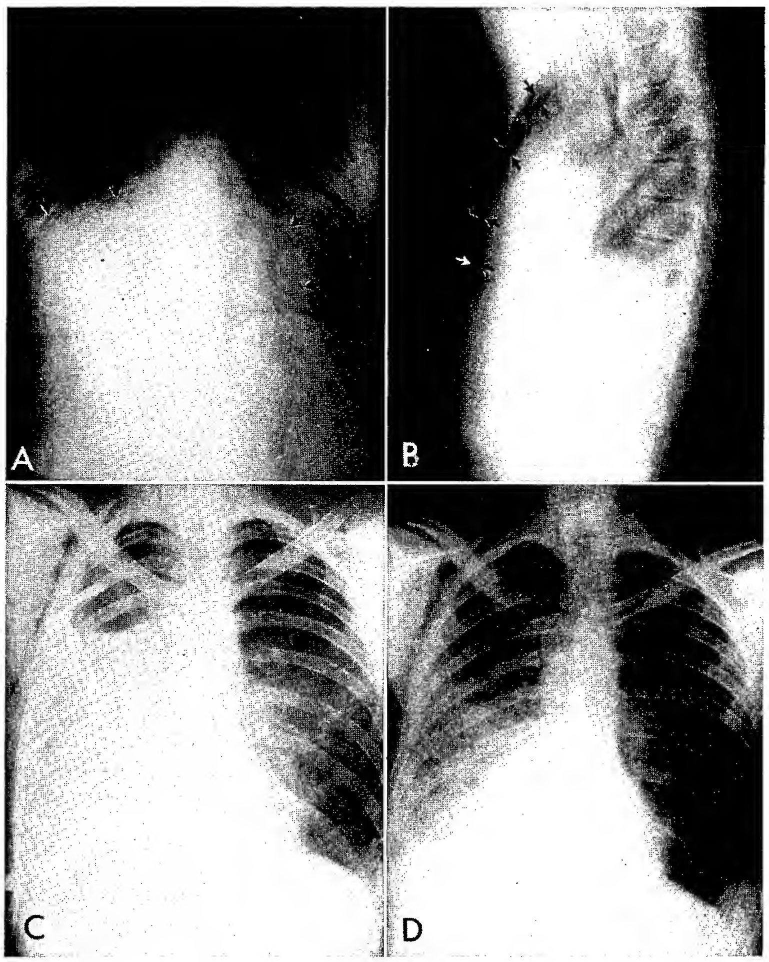

FIGURE 197 (case 1).—Serial roentgenograms in large defect of chest wall. A. Posteroanterior roentgenogram, 14 October 1944, immediately after wounding, showing fluid in lower half of right chest, with mottled infiltration above and on the left. Note air in anterior mediastinum outlining left mediastinal pleura. B. Lateral roentgenogram showing hazy lung fields and displacement of heart posteriorly by air in anterior mediastinum. C. Posteroanterior roentgenogram, 21 October 1944, showing closed drainage tube in right chest (reinserted to control pulmonary air leak), right hydropneumothorax, and subcutaneous and mediastinal emphysema. D. Posteroanterior roentgenogram, 25 October 1944, showing clearing of both lungs.

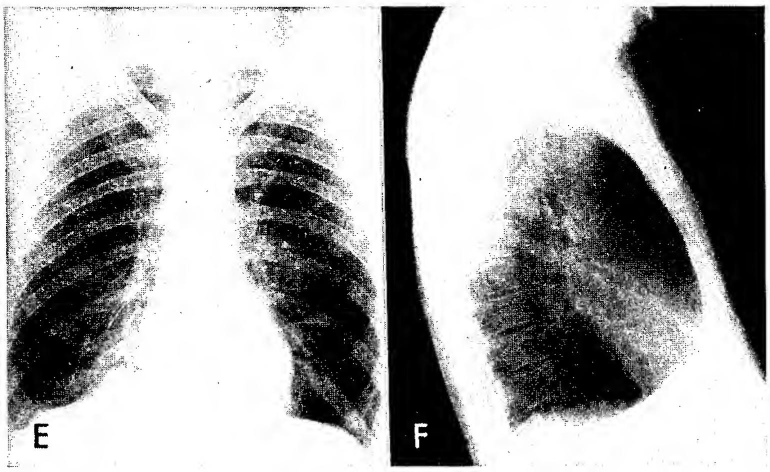

FIGURE 197.—Continued. E. Posteroanterior roentgenogram, 19 November 1960, 16 years after wounding, showing irregularity of fifth and sixth ribs anteriorly, slight blunting of right costophrenic angle, prominent bronchovascular markings, and fibrosis of right paracardiac region above diaphragm. F. Lateral roentgenogram on same date, showing pleural shadow anteriorly and fairly flat diaphragms.

Roentgenologic examination (fig. 197A and B) showed fluid occupying the lower half of the right chest, with a mottled infiltration above and to the left, and air in the mediastinum displacing the heart posteriorly.

When the patient was first observed, his pulse was intermittently irregular, and there were dropped beats at the radial pulse. There were also premature cardiac contractions. After 4 hours of the intensive resuscitation just described, his condition improved, and his lungs seemed entirely dry.

The sucking wound of the right chest was thoroughly debrided, and portions of the fourth, fifth, and sixth ribs, with the corresponding costal cartilages, were resected. The laceration of the right lung was repaired with interrupted sutures of fine catgut, and a drainage tube was introduced into the lower right pleural cavity and connected with a closed system.

To effect closure, it was necessary to mobilize a large pectoral flap and a rectus flap. These were sutured together and attached to the chest wall, to fill in the huge defect left by resection of the three ribs (fig. 196B). The central portion of the chest wall was closed (fig. 196C), and the wounds of entrance and exit were left open and packed with gauze down to the muscle layers.

A wound in the left upper arm was debrided.

The patient's condition was satisfactory throughout the operation, but an hour after it was concluded, his respirations became very wet. Bronchoscopy, which was performed at once, yielded a moderate amount of bloody mucus from both bronchi. At this point, cardiac arrest occurred. The catheter was at once withdrawn and the bronchoscope was removed. Oxygen was administered by

face mask, with intermittent positive pressure on the anesthetic bag. In less than 2 minutes, the heartbeat returned, the respirations also returned, and within 10 minutes, the patient regained consciousness.

Late on the second postoperative day, subcutaneous emphysema in the neck and the chest wall became quite marked. Pneumothorax, which was evident on the right, was controlled by a catheter inserted into the pleural space and fixed to a closed drainage system (fig. 197C). The inferior drainage tube ceased to function within 48 hours and was removed at this time.

The temperature was elevated to 101° F. for the first week after operation, but when the patient was evacuated to the base section on the 12th postoperative day, the emphysema had disappeared (fig. 197D), the lung was expanded, and the wound was clean.

Contrary to the usual practice, it was necessary in this case to use a tight binder during the postoperative period, because of the mobility of the chest wall. It was discarded as the wound healed and the wall became firm.

Management in the Zone of Interior.—The patient required no active treatment in the Zone of Interior and was given a disability discharge.

Followup.—This patient has been well since he was finally discharged from the VA outpatient clinics 5 years ago except for dyspnea on manual exertion and some pain. He has held a variety of jobs.

Roentgenologic examination on 19 November 1960, 16 years after wounding (fig. 197E and F) showed prominent bronchovascular markings, and slight fibrosis of the right paracardiac region above the diaphragm. The lateral view was clear except for blunting of the right cardiophrenic angle.

Comment.—This patient presented a number of problems: A large anterior sucking wound of the right chest; fractures of the fourth through the sixth ribs and their cartilages; some evidence of blast injury to the heart, with cardiac irregularity; a moderately severe wet lung syndrome; and mediastinal emphysema. Satisfactory closure of the large defect in the chest wall was effected with flaps of pectoral and rectus muscles. Although the patient had had atropine (gr. $\frac{1}{200}$) 90 minutes earlier, cardiac standstill occurred when bronchoscopy was performed after operation. Positive pressure oxygen was effective, and there were no further difficulties in this regard. Accumulation of air in the affected hemithorax required the insertion of a second closed thoracostomy tube. The explanation of the cardiac standstill was probably a combination of hypoxia, so-called cardiac blast, and vagovagal tracheal stimulation. The use of atropine before operation may have been helpful in producing the prompt recovery.

Case 2

Management overseas.—This technical sergeant, attached to a tank destroyer battalion, was wounded in the left chest by a high explosive shell fragment at 0845 hours on 3 December 1943, near Cassino, Italy. At the battalion aid station, a sucking wound of the left chest anteriorly (fig. 198A) was packed

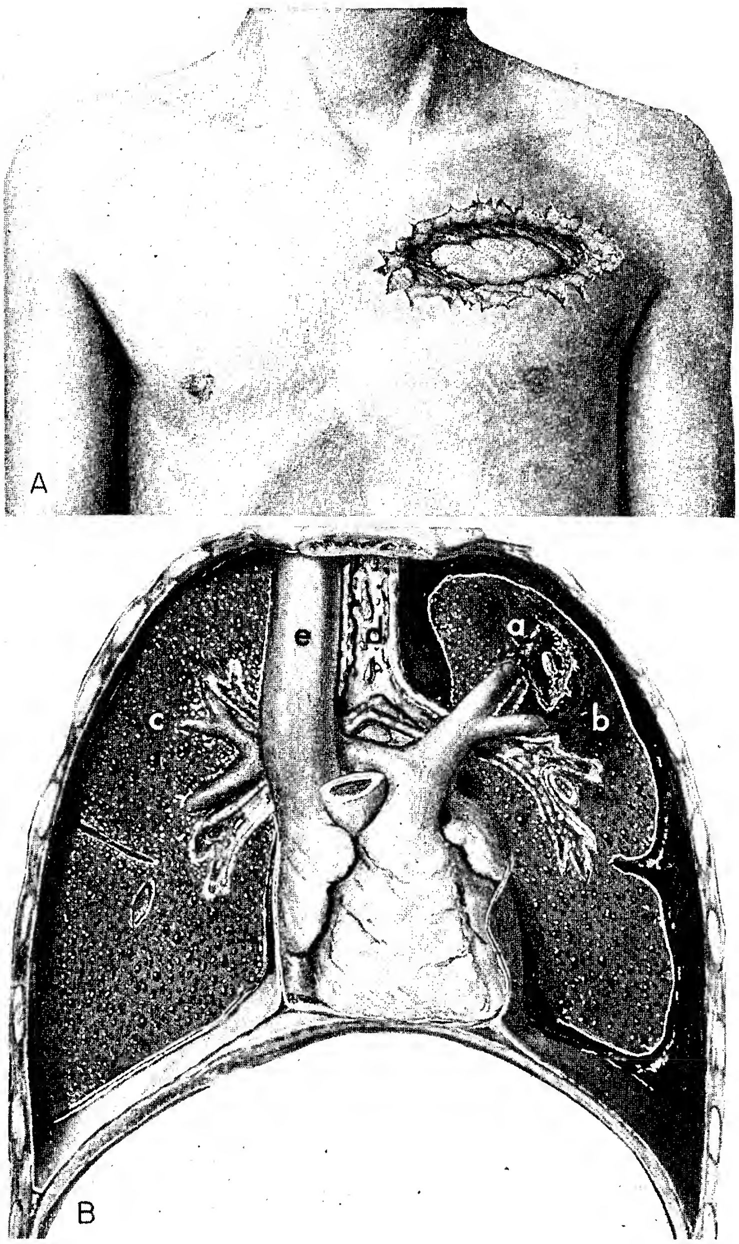

FIGURE 198 (case 2).—Schematic showing of sucking wound with defect of chest wall. A. Wound in anterior aspect of chest, with sucking wound of second intercostal space packed with petrolatum-impregnated gauze. B. Schema of pathologic findings, anterior view: Foreign body in lung and pleura (a), hematoma of left upper lobe (b), wet lung (c), mucus and blood in trachea (d), and engorged superior vena cava (e).

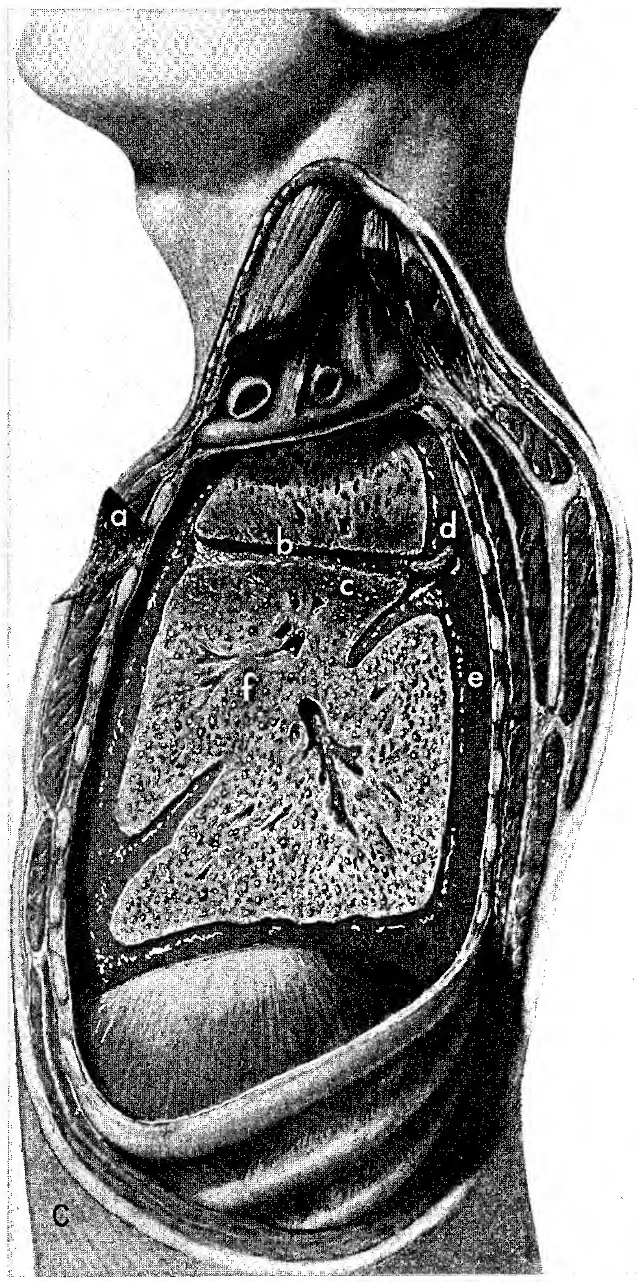

Figure 198.—Continued. C. Findings at thoracotomy, lateral view: Sucking wound (a), laceration of left upper lobe (b), hematoma of left upper lobe (c), foreign body in pleura (d), left hemothorax (e), and wet lung (f).

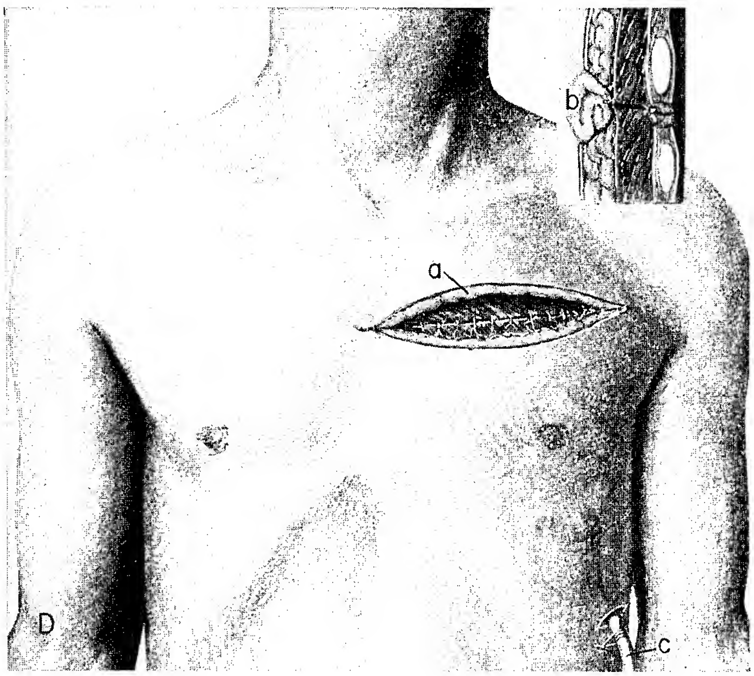

FIGURE 198.—Continued. D. Anterior aspect of chest at conclusion of operation: Debrided pectoralis major muscle sewn together to close sucking wound (a), with fine-mesh gauze packed into wound (b), and closed intercostal drainage tube (c).

with a dressing sprinkled with powdered sulfanilamide, and morphine (gr. ½) was given.

The patient was received at the 94th Evacuation Hospital at 1100 hours the same day. Here he gave a history of having had a severe respiratory infection for the previous 4 or 5 days. At this time, he was in shock, with blood pressure of 80/60 mm. Hg, pulse of 130, and wet and labored respirations. He was extremely dyspneic. Signs of fluid were present over the entire left chest, and rales were heard over the right chest.

The chest wound was fairly clean. It was cleansed down to the pleural opening, which was 2 by 3 cm., and a fresh petrolatum-impregnated pack was inserted. Resuscitative measures included tracheal aspiration, which yielded a large amount of bloody fluid; intercostal nerve block, from the second through the eighth nerves on the left; thoracentesis, which yielded 700 cc. of bloody fluid; and a transfusion of 500 cubic centimeters.

The patient's condition improved with these measures, but respirations were wet over both lung fields, and it was obvious that he had been wounded at a time when he had a severe bronchopulmonary infection. Therefore, since

the wound was fairly clean, it was decided that the risk of immediate surgery was greater, under the circumstances, than the development of infection of the chest wall.

Roentgenograms on the day of wounding, taken after aspiration of the chest (fig. 199A), showed a large foreign body in the left upper lobe and a hematoma in the same location.

The patient was given 4 gm. of sulfadiazine daily until 7 December 1943. During this period, he ran a low-grade temperature.

Operation was performed on 7 December 1943, under light nitrous-oxide anesthesia. The hematoma shown in the roentgenogram 4 days earlier was still present, but the foreign body was not readily accessible, and no search was made for it (fig. 198B and C). Lateral pleural drainage was instituted. The pectoralis muscle was closed (fig. 198D) and the rest of the wound was left wide open and packed.

The postoperative course was satisfactory, and the patient was evacuated to the 24th General Hospital at Bizerte, 10 days after operation. Here, 3 weeks later, elective thoracotomy was done, and a large foreign body was removed from the left pleural space and left upper lobe. Satisfactory healing followed delayed primary wound closure.

Four months after wounding, the patient was released for limited duty in the communications zone. At the end of the war, he was sent to the Zone of Interior by rotation and discharged there.

Followup.—A communication from this patient on 22 November 1960 stated that he had done outside construction work since the war. His only complaints were mild dyspnea when he had chest colds and some pain in the left shoulder associated with overwork. He was married and had children.

Roentgenograms made on 21 November 1960 (fig. 199B and C) showed the left lung completely expanded and no abnormalities of consequence.

Comment.—The interesting feature in this case is the admission of the patient to a forward hospital with a sucking wound superimposed upon a severe bronchopulmonary infection. It was decided to repack the wound daily and allow the respiratory infection to subside before surgical closure of wound was undertaken. Removal of the foreign body in the left pleura and upper lobe was performed at the base section. Recovery from this operation, as from the deferred initial wound surgery, with closure of the pectoralis muscle, in the forward hospital, was uncomplicated, and there was no residual disability.

This is the only case of the kind in this particular series, though there were a number of similar instances in the cases in this series not followed up after the war. The lesson to be learned from it is that, while general principles must be followed in wartime, they must be flexible enough to permit each case to be managed on its own merits.

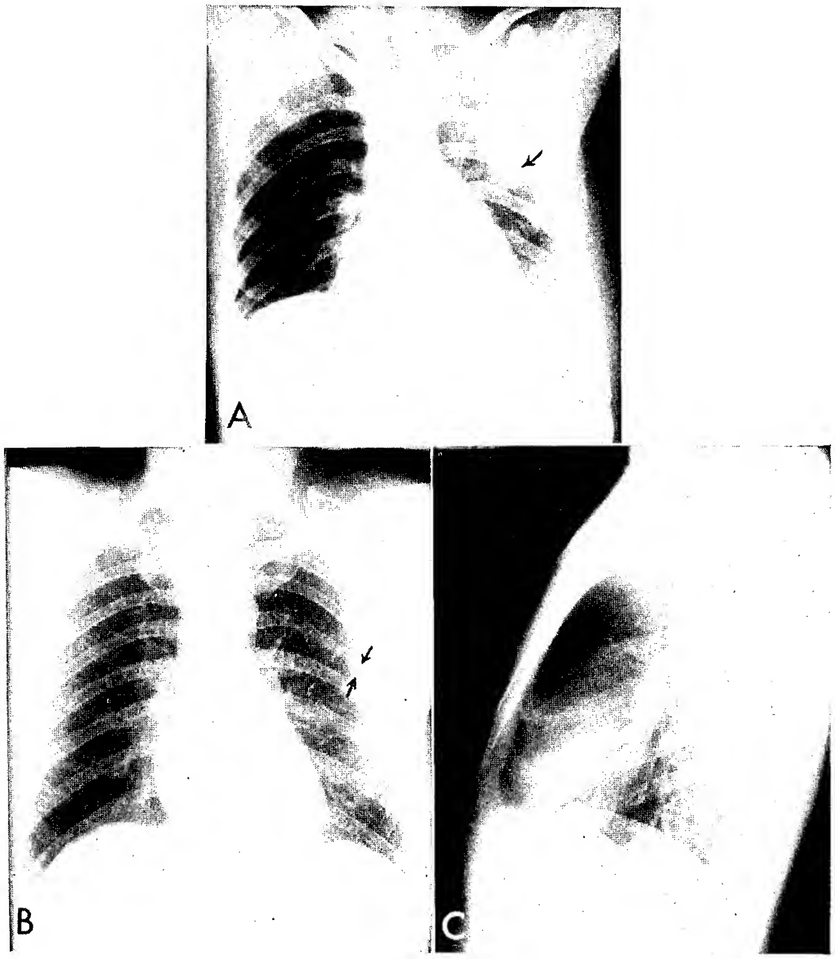

FIGURE 199 (case 2).—Serial roentgenograms in sucking wound with defect of chest wall complicated by severe bronchopulmonary infection. A. Posteroanterior roentgenogram, 3 December 1943, shortly after wounding, showing large foreign body and hematoma in left upper lung field, with haziness of both lung fields. Although the chest has been aspirated, a small amount of pleural fluid is still present on the left. B. Posteroanterior roentgenogram, 21 November 1960, 17 years after wounding, showing clear lung fields, prominent bronchovascular markings, and sharp costophrenic angles. Note healed fracture of left sixth rib, apparently the result of elective thoracotomy performed in base hospital in 1943. C. Lateral roentgenogram on same date showing clear lung fields and deep, clear costophrenic angles.

LACERATIONS OF THE LUNG

Lacerations of the lung of sufficient magnitude to present clinical problems were present in 61 of these 167 cases. Neither blunt trauma nor spontaneous pneumothorax was an etiologic factor in any case. In each instance, the lung was torn by a penetrating missile or by fractured ribs.

Intrapleural decompression was required in all 61 cases, but thoracotomy to repair the rent was employed only selectively. The laceration, per se, was not regarded as an indication for this procedure.

In 13 cases, continuing leakage of air was treated conservatively, by aspiration or catheter drainage, and in each instance, the laceration closed spontaneously. In a number of cases not included in the group followed up, small lacerations of the lung were closed when thoracotomy was done, but whether all these repairs were necessary is another matter.

In the 48 cases in this series in which thoracotomy was done on the indication of pulmonary lacerations, direct repair of the laceration was necessary in 38 cases, in 6 of which the tear was so extensive that muscle grafting was required to effect closure. This technique proved highly successful; neither bronchopleural fistula nor empyema developed in any instance.

In only one instance in the series was pulmonary resection carried out in a forward hospital. In this case, a laceration of the lung and damage to the blood supply and the bronchus of the posterior basal segment of the right lower lobe served as a valid indication for segmental resection because the damaged area of the lung was no longer viable.

Pulmonary resection was not necessary at any hospital in the communications zone, nor was it necessary in a Zone of Interior hospital. One patient among the 61 with pulmonary lacerations developed a pneumothorax in the Zone of Interior, 3 months after wounding, and thoracotomy was necessary to remove the foreign body causing the difficulty. No other patient in the series required surgery in the Zone of Interior, and this was the only thoracotomy performed for this reason in this series in any Army general hospital in the United States.

One other point should be emphasized in connection with lacerations of the lung: Patients in this group with progressive or tension pneumothorax were not evacuated to the rear until the condition was under control unless tactical circumstances demanded movement of the installation. In 2 of these 61 cases, evacuation was necessary for this reason before the air leak was controlled, but in each instance, a trained medical technician rode in the ambulance with the patient to insure that the decompression catheter functioned properly en route. This conservative evacuation policy undoubtedly explains why recurrent pneumothorax was not a problem in base section hospitals in the Mediterranean theater.

Case 3

Management overseas.—This 19-year-old infantryman was wounded in the left chest posteriorly, the left upper arm, and the left hip at 0800 hours on 28 November 1943, in the mountains near Cassino, by an artillery shell fragment. Emergency treatment consisted of the application of an occlusive dressing sprinkled with a sulfonamide powder, sulfadiazine by mouth, and morphine. At the collecting station, a unit of plasma was given. Because of transportation difficulties, the patient did not reach a clearing station until the following day.

When he arrived at the 94th Evacuation Hospital at LePezze, he was found to have a sucking wound (fig. 200A), satisfactorily occluded, of the left posterior chest in the region of the sixth, seventh, and eighth ribs, and smaller wounds of the left arm and left chest. He was extremely short of breath. The temperature was 101° F., the pulse 90, the respirations 48, and the blood pressure 130/80. Breath sounds were absent over the left chest; the right chest was fairly clear. Roentgenograms made on 30 October 1960 (fig. 201A and B) showed almost complete collapse of the left lung; fractures of the sixth, seventh, and eighth ribs; and a foreign body apparently within the cardiac shadow. Some fluid was present in the left chest; the right lung was fairly clear.

The routine of resuscitation included bronchial aspiration per catheter, after which respirations became more satisfactory.

Operation was performed on 30 November 1943, at 0040 hours. The posterior sucking wound, which was found to be infected (fig. 200A), was very carefully debrided down to clean muscle tissue. The instruments, gloves, and drapes were changed before the remainder of the operation was proceeded with.

Fractures of the sixth, seventh, and eighth ribs were exposed and the fragments were removed. The pleural cavity was entered by extending the wound of the sixth intercostal space (fig. 200B). A metallic foreign body, 2 by 1.5 cm., was removed from the left upper lobe, along with some rib fragments. A hematoma was present in this lobe, as well as a foreign body which did not penetrate the heart. Rib fragments were also removed from the left lower lobe (fig. 200C). Lacerations in both lobes, from which air was bubbling, were easily repaired with catgut (plain O) mattress sutures. About 500 cc. of blood was aspirated from the pleural space, after which extremely thorough pleural lavage was carried out.

The chest wall was closed (fig. 200D) by suturing the trapezius and latissimus dorsi muscles over the pleural defect in the sixth intercostal space. The serratus was closed more anteriorly. The fascia and subcutaneous tissues were left wide open. Closed intercostal drainage was instituted in the eighth intercostal space.

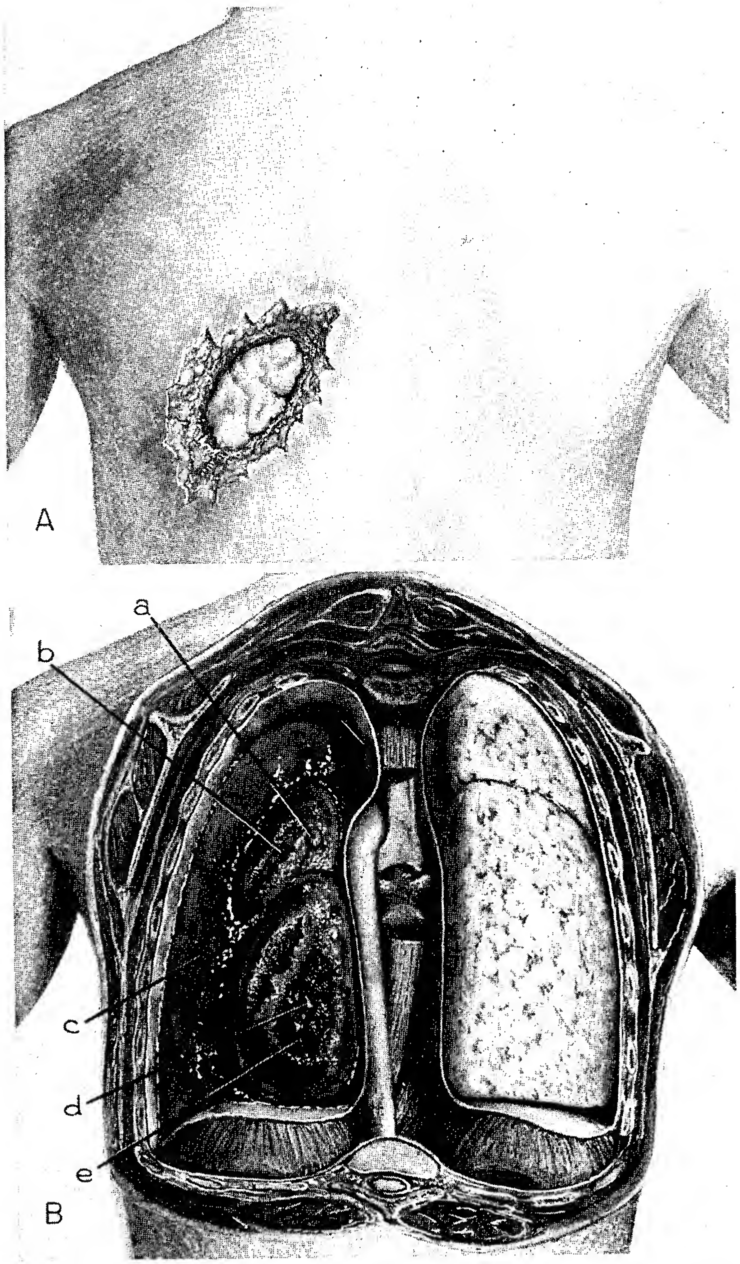

FIGURE 200 (case 3).—Sucking wound of left posterior chest with early infection. A. Wound. Posterior aspect of thorax showing infected sucking wound of sixth intercostal space on left, packed with gauze. B. Diagram of findings at thoracotomy showing: Collapsed lung with foreign body (a), pulmonary laceration (b), hemothorax (c), bone fragments in left lower lobe (d), and hematoma in same location (e).

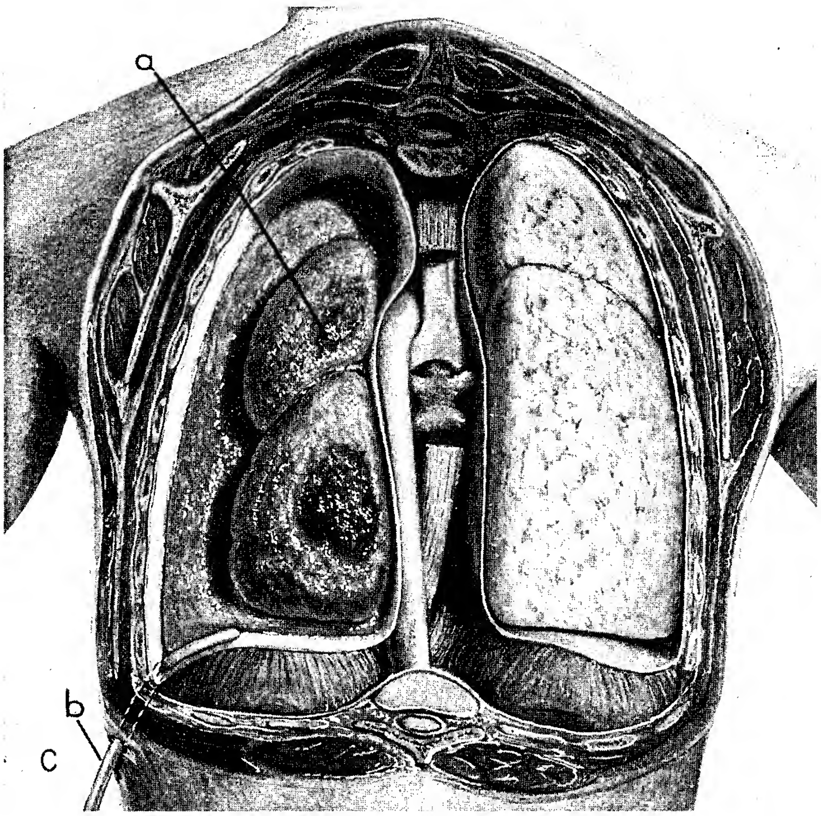

FIGURE 200.—Continued. Appearance of wound after repair of laceration of left upper lobe with removal of foreign body, leaving hematoma undisturbed (a). Closed pleural drainage has been instituted (b).

The immediate postoperative course was stormy, with the temperature ranging daily from 100° to 102° F. Roentgenologic examination on 7 December 1943 showed diffuse haziness of the left chest, and thoracentesis yielded purulent exudate.

In spite of the fever and the infection, the patient's general condition was good, and he was therefore evacuated to the base when an inordinate number of fresh casualties required that the hospital be emptied.

The left empyema was drained at the 33d General Hospital, at Bizerte, by resection of a portion of the ninth rib.

Management in the Zone of Interior.—In February 1944, the patient was evacuated to the Zone of Interior. By this time, the chest wound was healed, the empyema had been controlled, and the lung was fully expanded, the only abnormality being some pleural thickening on the left. Neurolysis of the left median nerve was carried out at Walter Reed General Hospital, Wash-

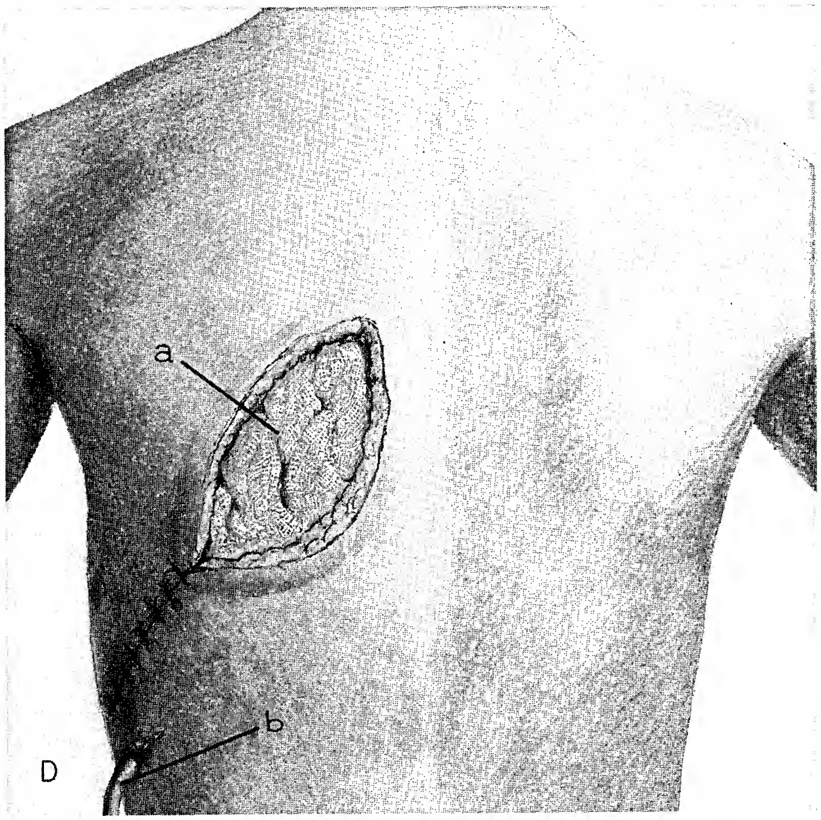

FIGURE 200.—Continued. D. Airtight closure of deep muscles of chest wall: Packing of superficial wound above closure (a), and closed pleural drainage (b).

ington, D.C. After a period of limited duty, the patient was discharged from the Army on 14 March 1946.

Followup.—A communication from the patient in November 1960 stated that he had worked in the post office as a mail clerk since his discharge from the Army. He was married and had two children. He had no symptoms referable to the chest. Roentgenograms made on 21 November 1960 (fig. 201C and D) showed an essentially clear left lung field. The only abnormality was regeneration and fusion of the sixth, seventh, eighth, and ninth ribs.

Comment.—This casualty was in serious condition when he was first seen, with an infected sucking wound of the left chest posteriorly, an almost complete collapse of the lung, some fluid in the left chest, and a foreign body at first thought to lie within the cardiac shadow. A hematoma was present in the left upper lobe, and there were fragments of fractured ribs in this lobe and in the left lower lobe. Conservative management included bronchial aspiration per catheter as part of the resuscitative regimen, debridement, removal of the

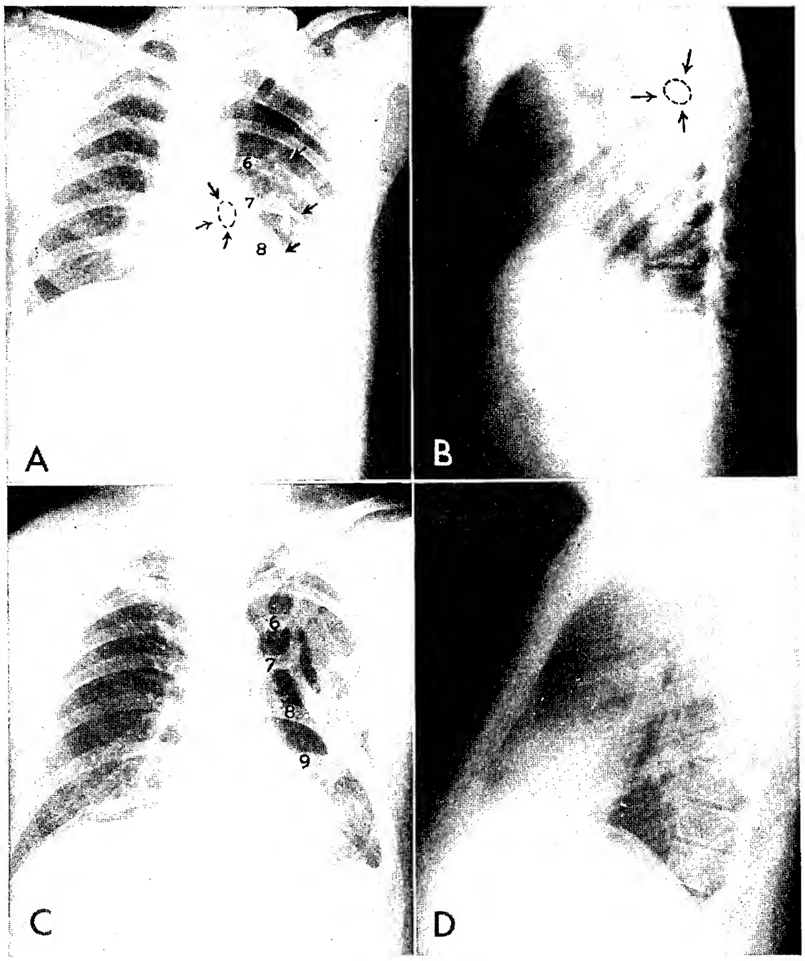

FIGURE 201 (case 3).—Serial roentgenograms of sucking wound with early infection. A. Posteroanterior roentgenogram, 30 October 1943, shortly after wounding, showing collapse of left lung and fracture of sixth, seventh, and eighth ribs. Note that in this view a foreign body appears to be within the cardiac outline. B. Left lateral roentgenogram, showing foreign body within lung and not penetrating heart. C. Posteroanterior roentgenogram of chest, 21 November 1960, 17 years after wounding, showing regeneration and bridging of sixth, seventh, eighth, and ninth ribs; slight blunting of left costophrenic angle; and slight pleural reaction on left. Otherwise, the lung fields are clear. D. Lateral roentgenogram on same date, showing clear lung fields and sharp posterior costophrenic sulci.

foreign body and the rib fragments, repair of lacerations in the involved pulmonary lobes, closure of the chest wall, and closed intercostal drainage.

Although the patient developed an empyema, it was readily controlled by correct rib-resection drainage, and the damaged lung was fully expanded when he was received in a Zone of Interior hospital. At the present time, 17 years after wounding, he is leading an active life, with no residua from his chest injury and no significant roentgenologic abnormalities.

This case is another illustration of the excellent results achieved by strict adherence to the principles and practices of thoracic surgery developed in the Mediterranean theater during World War II.

MEDIASTINAL INJURIES

Injuries to the mediastinum were recorded only 13 times in these 167 cases. This might be expected. As pointed out several times earlier in this history, because the heart, great vessels, esophagus, trachea, and bronchi are located in this area, most casualties with severe penetrating mediastinal wounds do not survive to reach any hospital.

The casualties in this series who survived mediastinal injuries all had wounds produced by small foreign bodies, whose driving force was spent. Bleeding into the mediastinum sufficient to produce a widened mediastinal shadow was present in five instances, but in all, the blood was absorbed without sequelae.

Although this is a small group and the mediastinal injury was not always the most important lesion, six of the casualties had traumatic thoracotomies, and others had considerable trauma to the thoracic cage and the lungs. Small foreign bodies were removed in four instances and allowed to remain in the others.

At the base section, five patients were returned to limited duty. The other five were evacuated to the Zone of Interior, where all received disability discharges, in one instance on the basis of psychoneurosis.

The problems encountered in the treatment of mediastinal injuries are illustrated in the following case history:

Case 4

Management overseas.—This 19-year-old Japanese-American infantryman received a high explosive shell-fragment wound of the left chest (fig. 202A) at 1100 hours on 8 November 1944, at Biffontaine, France. He received two units of plasma at the battalion aid station, where the wound was packed with a dressing sprinkled with sulfanilamide.

When the casualty was received at the 11th Field Hospital at 1345 hours, he was in deep shock. The blood pressure was 80/70 mm. Hg, the pulse 128, and the respirations 40. The massive sucking wound of the left anterior chest was occluded by an airtight packing.

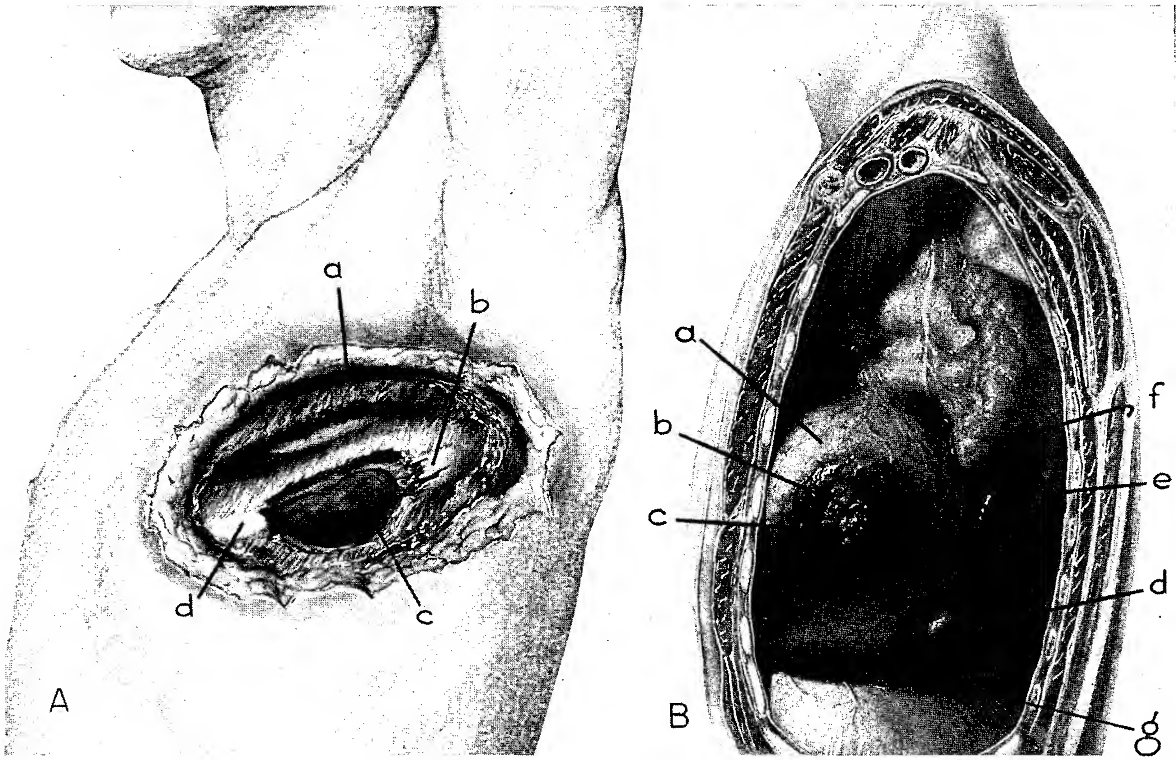

FIGURE 202 (case 4).—Anterolateral sucking wound of left chest. A. Anterolateral aspect of left chest after removal of petrolatum-impregnated gauze pack: Large, dirty wound, 5 by 8 inches, involving pectoralis major and serratus magnus (a), stump of fifth rib (b), defect in pleura 2.5 by 3 inches (c), and stump of fifth costal cartilage (d). B. Findings at thoracotomy: Tense hemopericardium (a), nonopaque foreign bodies (dirt, bone, cloth) in pericardium (b), hematoma of pericardium (c), hematoma of entire left lower lobe (d), laceration and hematoma of lingula of left upper lobe (e), accessory lobe (f), and hemothorax (3,000 cc.) (g).

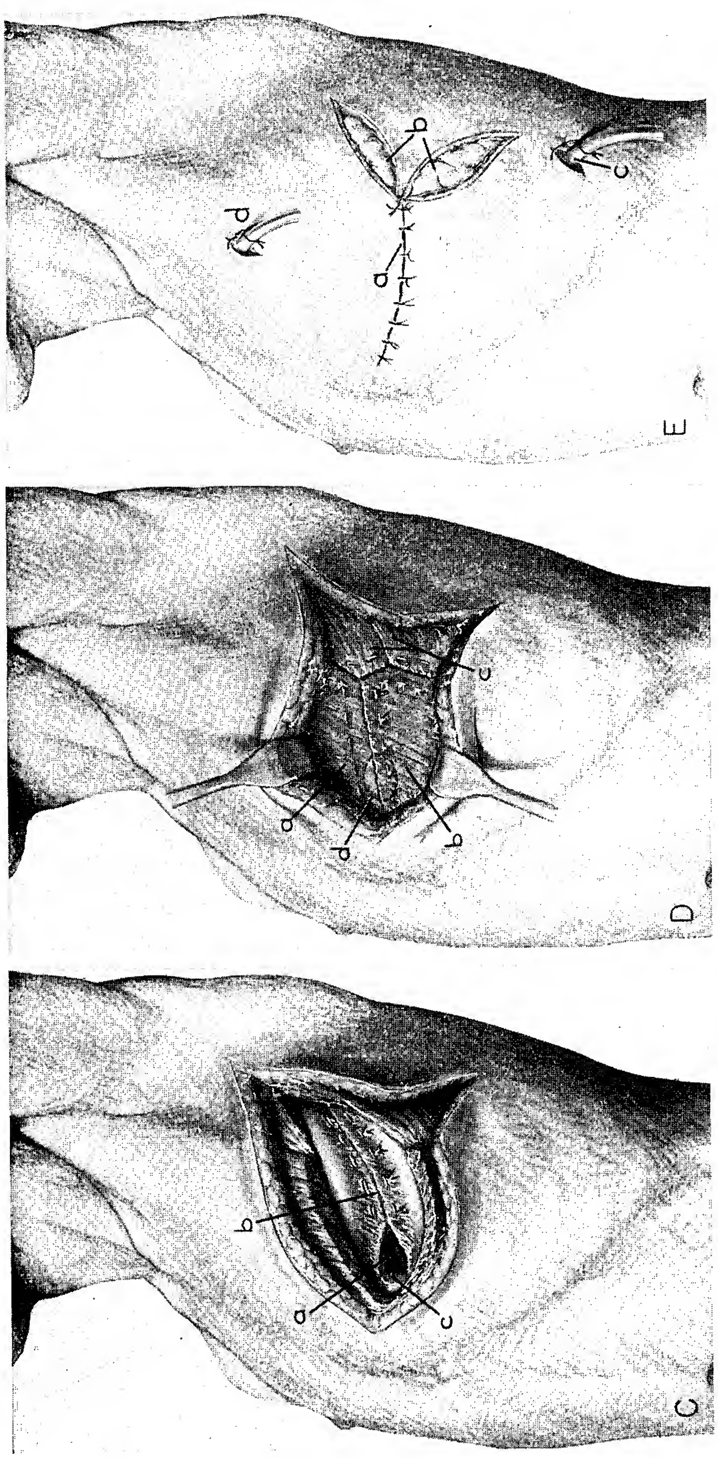

FIGURE 202.—Continued. C. First step in wound closure: Residual defect in pleura, 1 by 1.5 inches, impossible to close (a), closure of intercostal muscles (b), and anterior stump of fifth cartilage (c). D. Closure of muscles of anterior chest wall over pleural defect: Upper portion of pectoralis major (a), lower portion (b), serratus magnus (c), and pleural defect (d). E. Wound closure: Anterior reinforcement of closure by skin suture (a), skin wound left open posteriorly (b), posterior inferior closed intercostal drainage tube (c), and anterior intercostal closed drainage tube (d).

After 200 cc. of plasma had been given, pulmonary edema occurred, and no more plasma was given. Tracheal suction, repeated several times, produced quantities of thin, pinkish fluid. When only 20 cc. of fluid could be obtained by thoracentesis, the pack in the wound was temporarily loosened, whereupon a large amount of bloody fluid escaped. An attempt at blood transfusion precipitated pulmonary edema, and endotracheal suction was again applied, with positive pressure oxygen therapy, the anesthetic bag being squeezed with each inspiration.

Roentgenologic examination (fig. 203A and B) showed haziness of the entire left lung field, a shift of the heart to the right, and subcutaneous emphysema. The right lung was fairly clear.

At the end of 8 hours of the regimen described, the patient's condition was still precarious. Blood transfusion was again attempted, while at the same time, measures were carried out to combat wet lung. The blood pressure was imperceptible at times, but eventually, after intercostal nerve block and the administration of atropine gr. $\frac{1}{150}$, it rose to 96/60 mm. Hg.

After the patient's condition had improved sufficiently and his lungs had been dry for several hours, operation was undertaken at 0130 hours on 9 November, on the indications of continued intrathoracic hemorrhage; the necessity of closing the sucking wound; and the possibility of both diaphragmatic and cardiac injury. The operation began with debridement of the chest wall. The pectoralis and serratus muscles were extensively involved (fig. 202A), the defect measuring 5 by 8 inches. The fifth rib was shattered, and had to be removed down to the cartilage. There was an opening 2.5 by 3 inches in the fourth and fifth intercostal spaces.

Excellent exposure of the pleural cavity (fig. 202B) was obtained by opening the fifth intercostal space posteriorly. A massive hematoma occupied the lower lobe of the left lung and the lingula of the upper lobe, but the accessory lobe was not involved. About 90 cc. of bloody fluid was aspirated from the pericardium, which was extremely tense. After dirt, cloth, and fragments of rib were removed from the pericardium, it was seen to contain a large hematoma. A window was made in the pericardial sac, to permit drainage into the pleural cavity, which contained about 3,000 cc. of blood. After the blood had been removed, the cavity was thoroughly washed out with physiologic salt solution. A laceration in the upper lobe of the left lung had almost completely sealed over.

Pleural drainage was effected in the second intercostal space anteriorly and in the base posteriorly and was connected with a closed-drainage system.

By this time, the lung had expanded satisfactorily and there was no further evidence of bleeding. The chest wall was closed (fig. 202C and D) by partial closure of the intercostal bundles of the fifth interspace. The pectoralis major was mobilized from above and brought down over the pleural defect, and the serratus magnus was brought up behind. Since the muscles were abnormally thin, it was necessary to close the skin and subcutaneous tissues with mattress

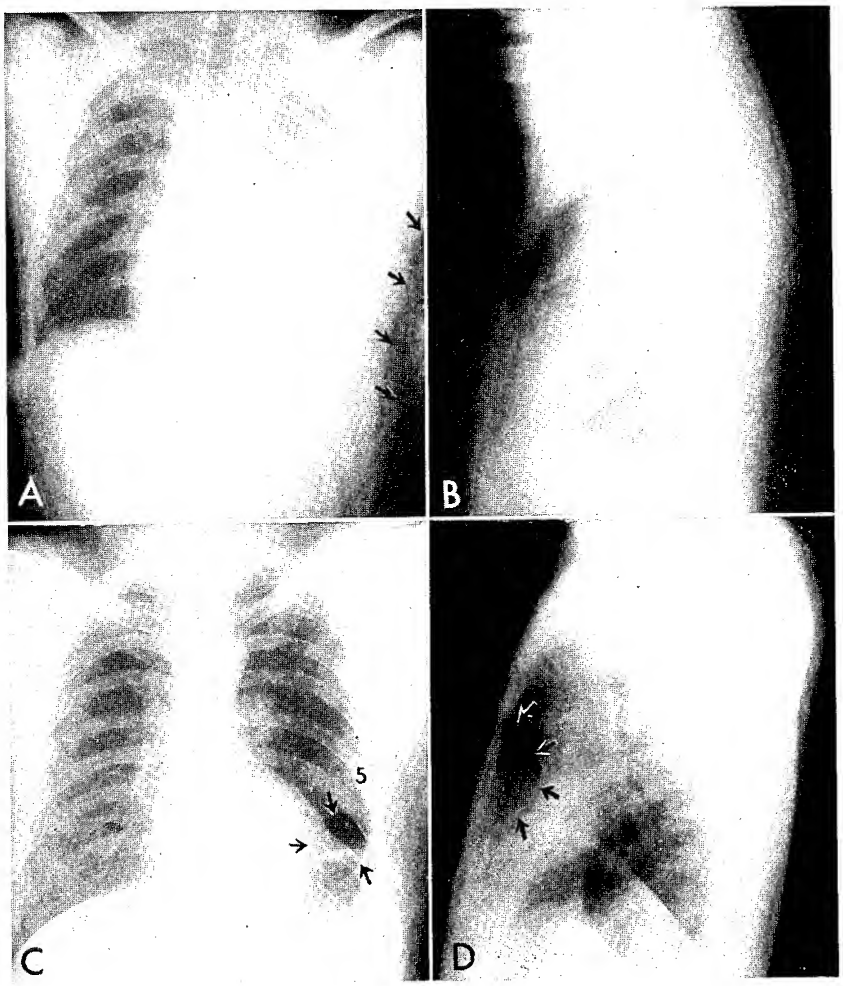

FIGURE 203 (case 4).—Serial roentgenograms in mediastinal injury with intrapericardial foreign bodies and hematoma. A. Posteroanterior roentgenogram, 7 November 1944, immediately after wounding, showing massive left hemothorax, with slight shift of mediastinum to right, and extensive emphysema of left chest wall. Right lung is fairly clear. B. Lateral roentgenogram on same date showing diffuse haziness. No radiopaque foreign body is seen. C. Posteroanterior roentgenogram, 22 November 1960, 16 years after wounding, showing clear lung fields and normal heart shadow. Note muscular defect of left anterior chest wall, with resection of anterior portion of fifth rib, and tenting of left diaphragm. D. Lateral roentgenogram on same date showing defect of left anterior chest wall with pleural reaction posterior to it and high anterior tenting of left diaphragm. Otherwise, the findings are within the normal range.

sutures anteriorly; both posterior limbs of the wound were left open (fig. 202E).

The wound in the left arm was then debrided. The ulnar nerve had been traumatized but not completely lacerated. The brachial artery, however, had been lacerated. After the clot which occluded it had been milked out and a free flow of blood had been reestablished, repair was accomplished with No. 00000 silk sutures. The pulse, which had not previously been present in the left wrist, could now be felt.

The patient made a satisfactory recovery.

Management in the Zone of Interior.—When the patient reached the Zone of Interior, no further surgery on the chest was necessary. Repair of the ulnar nerve was carried out at DeWitt General Hospital, Auburn, Calif. He was discharged from the Army on 17 August 1946.

Followup.—A communication from this patient on 23 November 1960 revealed that he was working 40 hours a week as a building materials salesman. He had no difficulty in breathing and no other complaints. Roentgenograms made on 22 November 1960 (fig. 203C and D) showed the left lung to be completely expanded and the lung fields clear. The chest wall defect was apparent on the film, both laterally and anteriorly, and the left diaphragm was tented, but there were no other abnormalities.

Comment.—This patient was observed at a field hospital in eastern France with a large sucking wound of the anterior chest wall, which undoubtedly involved both the lung and the heart. Stabilization was extremely difficult and occupied some 10 hours. Although surgery was taxing, he withstood it well; it included removal of foreign bodies from the pericardium, pericardial drainage, and the structural problem inherent in the reconstruction of the anterior chest wall. The pectoralis and serratus muscles were used to cover the defect, and the weakest portion of the repair was reinforced by closure of the skin over it. The associated wound in the arm, which involved both the ulnar nerve and the brachial artery, also required a taxing repair.

The fact that this patient is well and working without complaints referable to the chest 16 years after wounding is heartening when one considers the severity of the original wound and the complex problems involved in both resuscitation and initial surgery. The presence of clear lung fields, except for diaphragmatic tenting, at the end of this period of time also speaks well for the staged management employed in this case.

BLAST INJURIES

Generalized blast injury, caused by a wave of generalized positive pressure followed by a wave of negative pressure, was a factor in 21 cases in this series. In three instances, there was no external wound except for powder and dirt burns of the skin. Perforated eardrums were present in four cases,

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and transient cardiac irregularities and evidences of cerebral anoxia were characteristic of the early stages in practically all cases.

All 21 patients were evacuated to the base section, where 3 patients died of wounds not directly due to the blast injury. After periods of up to 5 months, six patients were returned to limited duty in the communications zone. The other 12 patients were returned to the Zone of Interior. None of them was released for active duty, and all of them eventually received disability discharges, two with the diagnosis of psychoneurosis as the principal cause. Followup studies showed slight pulmonary emphysema, but no instance of clinical dyspnea was reported.

Localized blast effect, due to the impact force of high explosive shell fragments upon the chest wall and thoracic organs, was a factor in practically every patient in the series who had a severe injury of the chest wall.

The following case history illustrates the problems of blast injuries and the typical followup status of those who sustained them:

Case 5

Management overseas.—This 21-year-old infantryman was 20 feet away from an aerial bomb blast which occurred at 1330 hours on 10 November 1943, near Venafro, Italy. He was unconscious for a short period of time. When he regained consciousness, he found that he had been sprayed with dirt and had suffered facial burns. He was picked up by a corpsman shortly after the blast and taken to a battalion aid station, where he was given 250 cc. of plasma and morphine gr. ½.

When he was admitted to the 94th Evacuation Hospital at LePezze at 1530 hours, he complained of severe dyspnea, orthopnea, wheezing, choking, slight dysphagia, and severe chest pains. Coughing produced bloody sputum.

Examination showed a second degree burn of the face, involving the left cornea and conjunctiva, but no other external wounds. The veins in the neck were full. The patient was cyanotic, and his breathing was extremely difficult. Breath sounds were decreased, and in some areas almost absent, over the right chest, and scattered rales were also heard on the left. The heart sounds were distant and slightly irregular.

The left tympanic membrane was ruptured. Hearing was impaired on this side, and later there was slight drainage from the ear.

Roentgenologic examination on 11 November 1943, the day after injury (fig. 204A), showed diffuse bilateral haziness and infiltration, which were taken to indicate petechial pulmonary hemorrhage and edema.

Treatment consisted of oxygen administration by nasal catheter, repeated catheter bronchial aspiration, restriction of fluids by mouth, and control of the chest pain by small doses of morphine. The patient was not digitalized, and he was not given intravenous fluids.

The lungs gradually cleared (fig. 204B), and 14 days after wounding, he was evacuated to a base hospital.

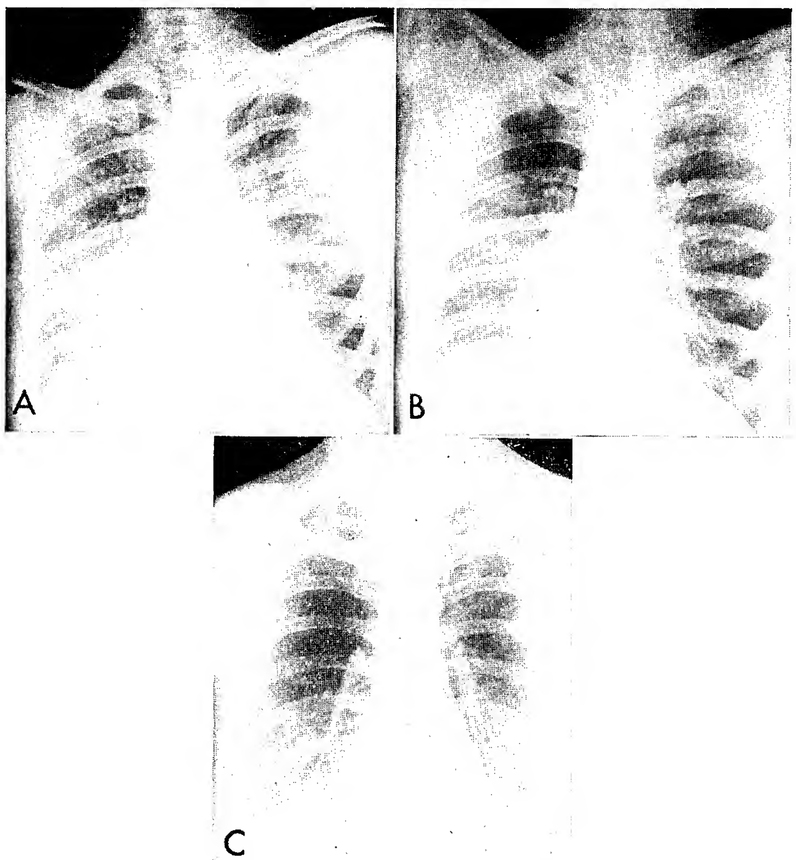

FIGURE 204 (case 5).—Serial roentgenograms in blast injury. A. Posteroanterior roentgenogram, 11 November 1943, 24 hours after injury, showing diffuse bilateral haziness and infiltration indicative of petechial pulmonary hemorrhage and edema. B. Posteroanterior roentgenogram, 17 November 1943, showing clearing of lung field. C. Posteroanterior roentgenogram, 7 January 1960, 16 years after severe blast injury. The only abnormality is slight emphysema of upper lobes. The diaphragms are at level of the eleventh ribs; their contours are rounded. Heart is also normal.

Management in the Zone of Interior.—In the Zone of Interior, the patient required no treatment for the blast injury. The considerable facial scarring left by the powder burns was treated by plastic surgery at Valley Forge General Hospital, Phoenixville, Pa., in March 1944. On 28 November, he was returned to limited duty and served without difficulty until his discharge on 1 September 1945.

Followup.—Since his discharge from the Army, the patient has been followed up in the Veterans' Administration. His only complaint is brief, mild headaches, about three times a week, relieved by simple medication. They are

thought by the neurologist to be evidence of an early, mild, chronic brain syndrome as a result of the blast injury.

Roentgenologic examination on 7 January 1960, 16 years after the blast injury (fig. 204C), showed no abnormality except mild pulmonary emphysema of the upper lobes.

Comment.—This case history illustrates a typical blast injury, produced by a powerful wave of positive, followed by a wave of negative, air pressure, from a bomb apparently of considerable size. The infantryman was about 20 feet from the bomb, his nearness to it being shown by the superficial burns and dirt wounds of the skin of the face. The symptoms and signs were those usually observed in serious blast injuries. They included unconsciousness, severe dyspnea, hypoxia, severe chest pain, and rupture of an eardrum. The dilatation of the veins of the neck indicated increased venous pressure, and the wet lung syndrome was characterized by the presence of persistent rales and rhonchi.

Treatment included maintenance of a clear airway by repeated catheter aspirations; the administration of oxygen, to provide adequate oxygenation of the blood while the lung was healing; restriction of fluids by mouth; and avoidance of administration of fluids by vein. With these measures, digitalization was not necessary.

This casualty could be returned to active duty, and 16 years after the blast injury, he is in good health and is leading an active life. He has no pulmonary symptoms and there are no significant roentgenologic findings. The only (minimal) evidence of the injury takes the form of occasional mild headaches.

THORACOABDOMINAL WOUNDS

Thoracoabdominal wounds, which occurred 25 times in these 167 thoracic wounds, represented the combined problems encountered when two major serous cavities were involved. The seriousness of these problems is evident in certain facts:

1. Three casualties, as already mentioned (p. 450), died of late complications in base hospitals.
2. No patient in this group was returned to duty from the forward area, although four performed limited duty in base sections of the Mediterranean or European theaters within 2 months after wounding.
3. Secondary surgery was required in six cases, three times for drainage or empyema, twice for drainage of subphrenic infections, and once for removal of a foreign body which was left in situ in the forward area because of the urgency of the abdominal wounds.
4. All patients who returned to the Zone of Interior eventually received disability discharges, in one instance almost 10 years after wounding.

The following case histories illustrate the course of, and the problems involved in, thoracoabdominal wounds:

Case 6

Management overseas.—This 22-year-old infantryman was wounded in the left lower chest anteriorly (fig. 205A) at 1200 hours on 28 September 1944, at Faucompierre, France. He was standing about 100 feet from an 88-mm. shell explosion. He was knocked down but did not lose consciousness. Within 15 minutes, he was taken to a battalion aid station, where he was given eight sulfonamide tablets by mouth and a unit of plasma intravenously. The wound was sprinkled with a sulfonamide powder and dressed.

When he was admitted to the 11th Field Hospital at Eloyes, France, the wound was bleeding moderately. He complained of moderate pain in the chest and severe pain in the left upper quadrant of the abdomen. The blood pressure was 120/78 mm. Hg, the pulse 80, and the respirations 20.

The wound in the lower left chest was close to the costal margin in the eighth intercostal space. It was packed because movement of the chest wall caused sucking. Breath sounds on the left were decreased, but the right lung showed no abnormalities.

The patient complained of increased pain in the abdomen immediately after admission to the field hospital. Examination revealed tenderness in the left upper quadrant; pressure on any portion of the abdomen produced pain in this area.

Roentgenologic examination (fig. 206A) showed a large metallic foreign body below the left diaphragm, at the level of the eleventh rib. The lung fields were hazy.

The patient had eaten a K-ration 5 hours before wounding, and gastric lavage produced undigested food along with bloody fluid.

Obviously, peritoneal contamination had occurred from a wound of the gastrointestinal tract, and operation was urgent. At 1530 hours, when the anesthesiologist began induction, the blood pressure fell to 40/0 mm. Hg. After a transfusion of 500 cc. was given, the systolic pressure rose to 90 mm. Hg, and operation was restarted at 1630 hours.

The wound at the eighth intercostal space was debrided and the incision was extended along this interpace (fig. 205A), to expose the pleural cavity. The diaphragm was found widely torn. The omentum had herniated into the left pleural cavity, which also contained gastric contents. When the diaphragm was opened posteriorly, providing excellent exposure of the upper abdomen (fig. 205B and C), an 8-cm. tear was found in the stomach. Both the spleen and the pancreas were lacerated. The foreign body responsible for these wounds, which was 4 by 1 by 2 cm., had dropped back into the stomach. It was removed, after which the gastric laceration was repaired and the spleen was removed. Blood in the amount of 1,000 cc. was aspirated from the peritoneal cavity, which also contained a small amount of gastric contents. The rent in the gastrocolic omentum was repaired. The diaphragm was closed with a double layer of interrupted silk sutures. The chest wall was closed in layers with similar suture material. Closed intrapleural drainage was instituted.

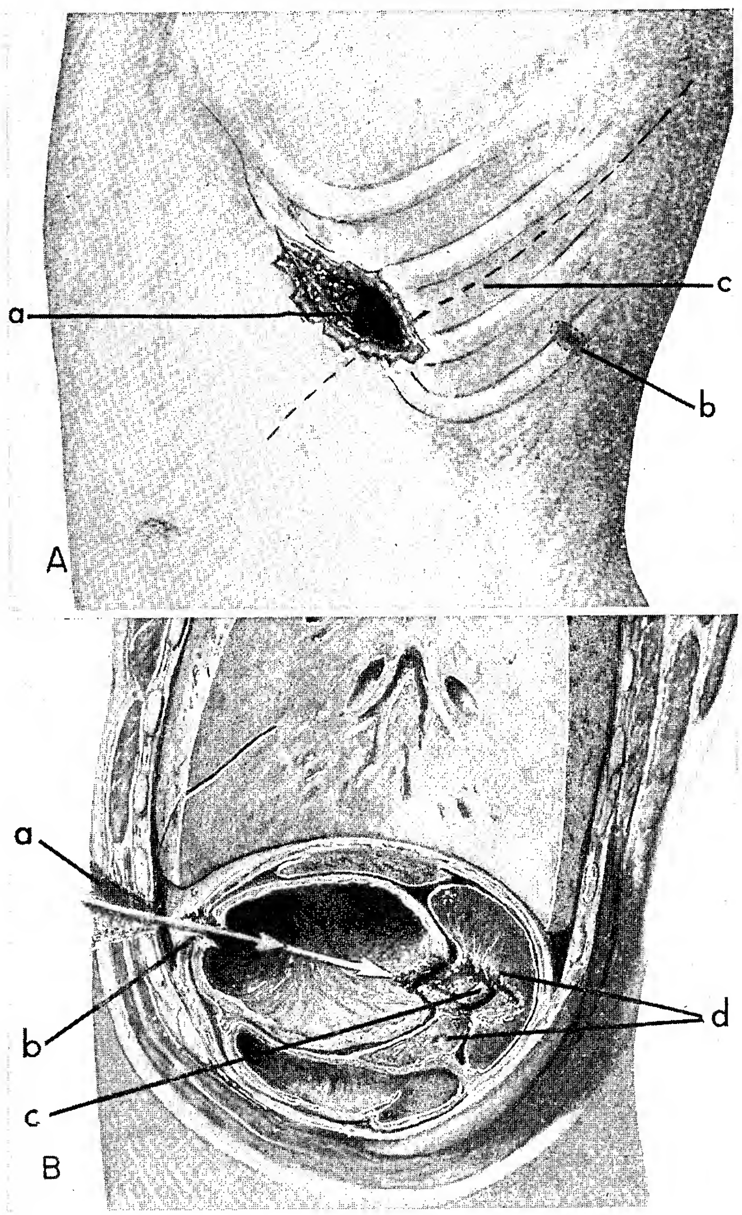

FIGURE 205 (case 6).—Schematic showing of thoracoabdominal wound. A. Wound of entrance: Shell fragment wound in anterior eighth intercostal space (a), metallic foreign body (b), and incision in eighth intercostal space (c). B. Diagram of course of missile: Wound of chest wall (a), laceration of diaphragm and stomach (b), foreign body (c), and laceration of spleen and pancreas (d).

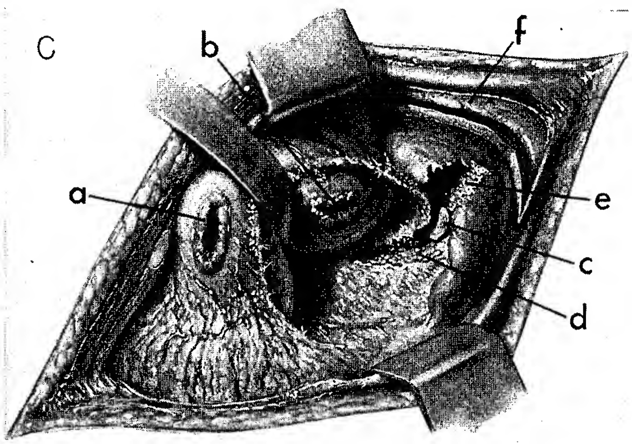

FIGURE 205.—Continued. C. Excellent exposure of left upper abdomen at operation, with diaphragm opened and rib spreaders in place: Anterior wound in stomach (a), posterior wound in stomach (b), foreign body (c) responsible for lacerations of pancreas (d), spleen (e), and left lower lobe of lung (f).

The immediate postoperative recovery was satisfactory, but on the following morning, the patient was dyspneic and cyanotic, and diffuse rales were heard over both lungs. Thoracentesis produced 500 cc. of bloody fluid. Because the hematocrit showed hemoconcentration, an intravenous infusion of glucose and physiologic salt solution was given, together with 250 cc. of plasma. Bilateral intercostal nerve block was carried out from the sixth through the twelfth nerves. The penicillin therapy begun before operation was continued. Thereafter, the patient coughed and raised sputum, and the lungs cleared.

On the eighth postoperative day, peristalsis was active, and fluids were permitted by mouth. On the 10th postoperative day, signs of consolidation were demonstrable in the right lower lobe, and some fluid was present. Bronchoscopy produced thick mucus from the right lower, middle, and upper lobes, and a small amount from the left side. The temperature ranged from 100° to 101° F.

Roentgenologic examination on the 13th day (fig. 206B) revealed fluid and infiltration in the lower two-fifths of the right lung field and fluid in the left costophrenic angle. Because of the pneumonitis and fluid on the right side, subphrenic abscess was considered a paramount diagnostic possibility. On the 19th postoperative day, thoracentesis produced 700 cc. of clear fluid from the right pleural cavity. Roentgenologic examination (fig. 206C) after this procedure still showed pleural fluid bilaterally, especially on the right.

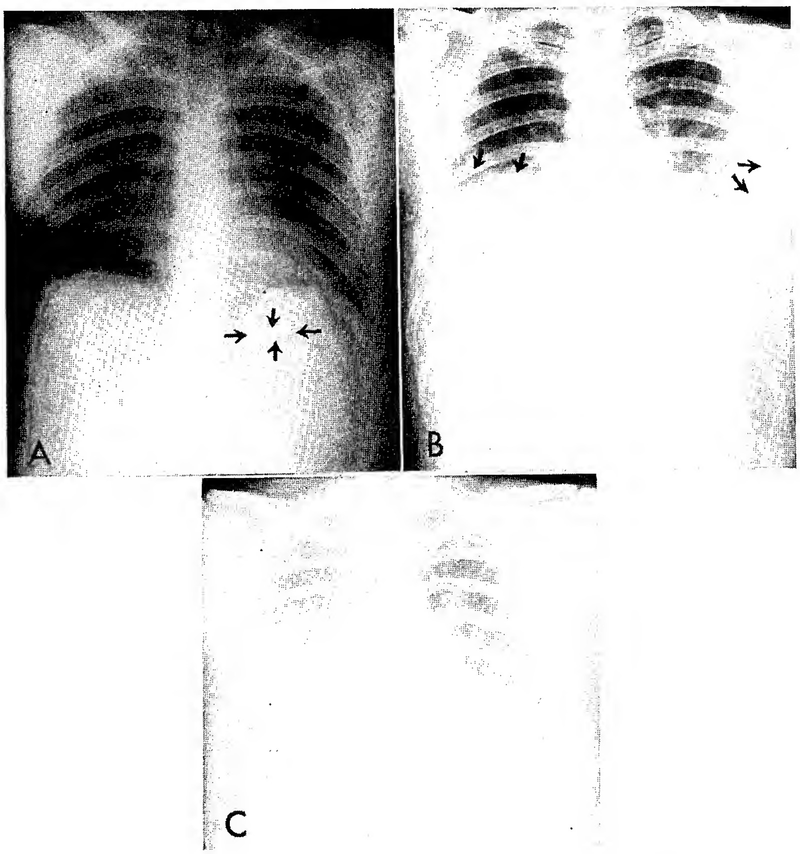

FIGURE 206 (case 6).—Serial roentgenograms in thoracoabdominal wound. A. Posteroanterior roentgenogram, 28 September 1944, immediately after wounding, showing large metallic foreign body below left diaphragm, at level of eleventh rib, with haziness of both lung fields. B. Posteroanterior roentgenogram, 11 October 1944, showing fluid in left costophrenic angle and fluid and infiltrative process in lower two-fifths of right lung field. C. Posteroanterior roentgenogram, 19 October 1944, showing fluid in both pleural cavities, more marked on right.

On the following day, the patient was evacuated to the 36th General Hospital at Dijon, France. Here the pleural effusion on the right gradually resolved. On the left side, the fluid became purulent and rib-resection drainage was required. A subphrenic infection did not develop.

Management in the Zone of Interior.—At Fitzsimons General Hospital, Denver, Colo., to which the patient was evacuated, the empyema pocket on the left side gradually became obliterated without further surgery. The patient was considered for limited duty, but with the end of the war in Europe and the reduced necessity for manpower, he was given a disability discharge on 28 May 1945.

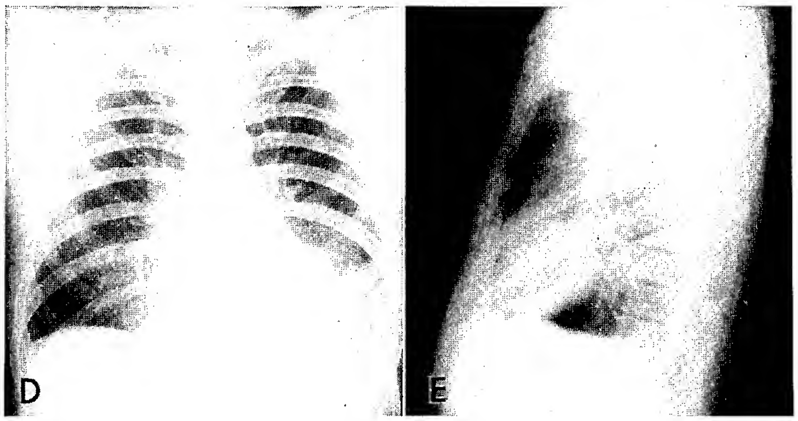

FIGURE 206.—Continued. D. Posteroanterior roentgenogram, 19 November 1960, 16 years after wounding, showing lung fields clear except for pleural shadow above diaphragm and deformity of rib in lower left costophrenic angle as result of rib resection for empyema. E. Lateral roentgenogram on same date, showing blunting of anterior cardiophrenic sulcus. Posterior sulci are sharp, and lungs are clear.

Followup.—Following his discharge, the patient returned to an active civilian life. At this time (November 1960), he is still working hard as a maintenance worker in a large city. The work at times involves manual labor, but he wrote that he had "no ill effects from his injury" and considered himself perfectly well.

Roentgenologic examination on 19 November 1960, 16 years after wounding (fig. 206D and E), showed clear lung fields except for blunting of the lower left costophrenic angle as a result of rib resection for empyema, with some blunting of the anterior cardiophrenic sulcus.

Comment.—This casualty had serious injuries, including a sucking wound of the chest; a tear of the diaphragm; and lacerations of the stomach, spleen, and pancreas. Severe blood loss and early contamination of the pleura and peritoneal cavities with gastric contents made resuscitation difficult. The spleen was removed, and the stomach, pancreas, and diaphragm were repaired. The course after operation was stormy, as a result of bilateral pleural effusion and pneumonitis. The right side cleared under penicillin and sulfonamide therapy, combined with aspiration of the chest. Empyema developed on the left side, as a result of early soiling of the pleura with gastrict contents. Recovery followed drainage of the left empyema, with a complete return to health. At the end of 16 years, this man has no residual symptoms and is hard at work.

Case 7

Management overseas.—This 23-year-old sergeant in a chemical warfare battalion sustained bilateral shell-fragment wounds of the posterior chest at 2130 hours on 10 December 1944, at Enchenberg, France. He was given four

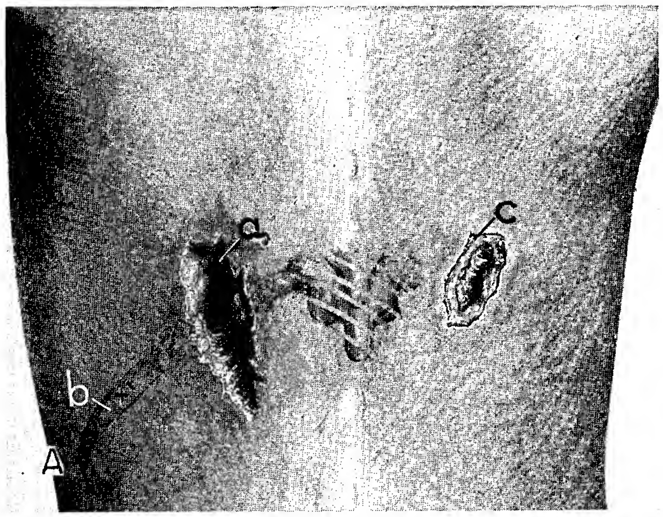

FIGURE 207 (case 7).—Schematic showing of thoracoabdominal wound. A. Wounds: Sucking wound over left eleventh rib posteriorly (a), fracture of eleventh rib (b), and nonsucking wound in right chest posteriorly (c).

units of plasma and two injections of morphine at a battalion aid station. The sucking wound in the left chest was packed.

When he was admitted to the 54th Field Hospital at 0200 hours on 11 December, he was comatose, apparently from shock and from the two injections of morphine. The blood pressure was 90/60 mm. Hg, the pulse 130, and the respirations 36. His respirations were wet and labored.

Examination revealed shell-fragment wounds of the right and left chest posteriorly. The wound on the left side was sucking (fig. 207A). Roengenologic examination (fig. 208A) revealed massive opacity of the left chest, haziness of the right lung, and a large amount of gas in the stomach. After gastric decompression, another examination (fig. 208B) showed a foreign body in the upper part of the left upper lobe.

Resuscitation was begun immediately and continued for 14 hours. It included, in addition to gastric decompression, catheter suction of the tracheobronchial tree, intratracheal oxygen administration under positive pressure, and the slow transfusion of 1,000 cc. of blood.

At the end of this period, the lungs were clear and the blood pressure had stabilized at 112/72 mg. Hg. The patient was therefore taken to the operating room and, under endotracheal anesthesia, the pack was removed from the sucking wound of the left lower posterior chest. The wound was debrided down to the pleura, after which it was extended upward and laterally along the eleventh intercostal space. The eleventh rib was divided to improve exposure (fig. 207B). The kidney capsule was torn, and there was a rent 3 by

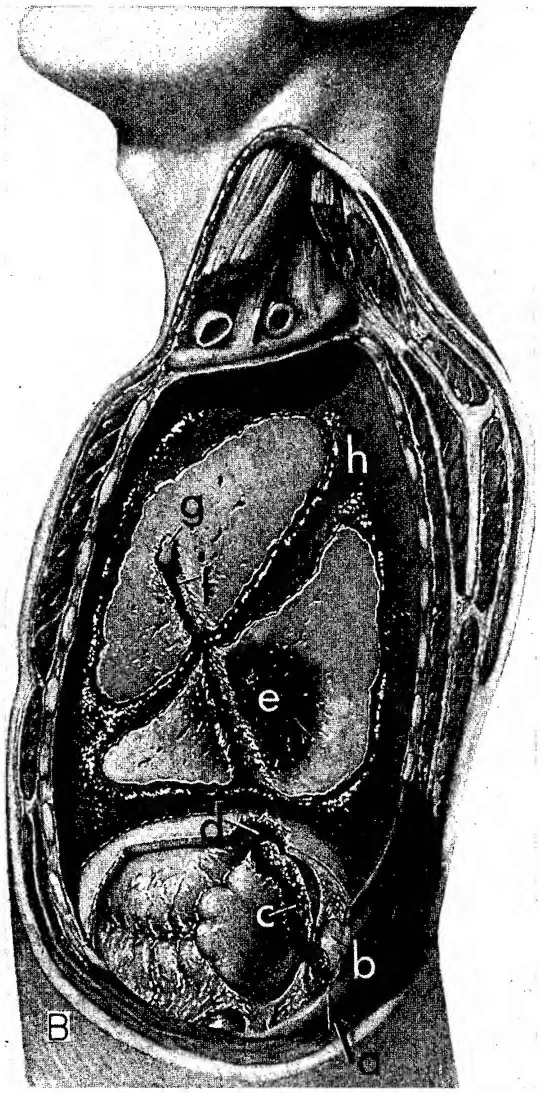

FIGURE 207.—Continued. B. Diagram of course of shell fragment in abdomen and thorax: Sucking wound of entrance (a), laceration of upper pole of kidney (b), severe laceration of spleen (c), laceration of diaphragm (d), laceration and hematoma of left lower lobe (e), laceration of left upper lobe (f), shell fragment in lung (g), and massive hemothorax (h).

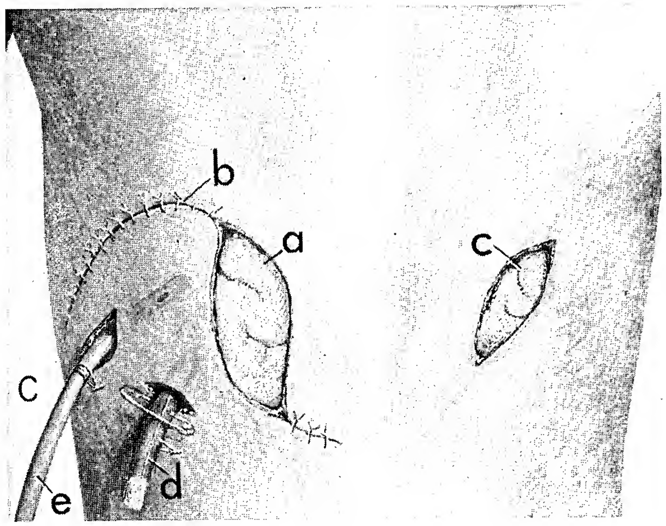

FIGURE 207.—Continued. C. Posterior view of chest: Central portion of wound packed down to sutured muscle layers (a), closure of skin at both ends of incision (b), wound in right posterior chest wall after debridement and packing with fine-mesh gauze (c), Penrose drain to left kidney (d), and closed thoracostomy drainage tube (e).

1 cm. in the posterior lateral portion of the upper pole. A catheterized specimen had shown blood. Bleeding was controlled with catgut sutures, so that it was not necessary to remove the kidney. The spleen, which was badly torn and bleeding, was removed; the artery and vein were controlled with mattress sutures of No. 00 silk. The diaphragm, which was torn near the dome, was opened anteriorly, to provide adequate exposure of the inferior pleural cavity. The lower left pulmonary lobe, which was lacerated and the site of a hematoma, was oozing moderately; it was repaired with fine catgut sutures. About 800 cc. of blood was aspirated from the pleural cavity.

Since the upper pulmonary lobe expanded fairly well at this point, it was decided to remove the foreign body. It was left in situ, however, when exposure proved inadequate and there was no evidence of leakage of air or bleeding from the affected area. Closed catheter drainage was instituted in the eighth intercostal space.

The diaphragm was debrided and closed with interrupted sutures of No. 00 silk. Sulfanilamide (3 gm.) and penicillin (100,000 units) were left in the upper abdominal cavity. The kidney was drained with a Penrose sheath drain through a stab wound in the flank.

The latissimus dorsi was closed over the defect in the eleventh intercostal space in the central portion of the wound, which had been debrided, and this area was packed with gauze down to the muscle layer (fig. 207C). The anterior and posterior extensions of the wound were closed in layers.

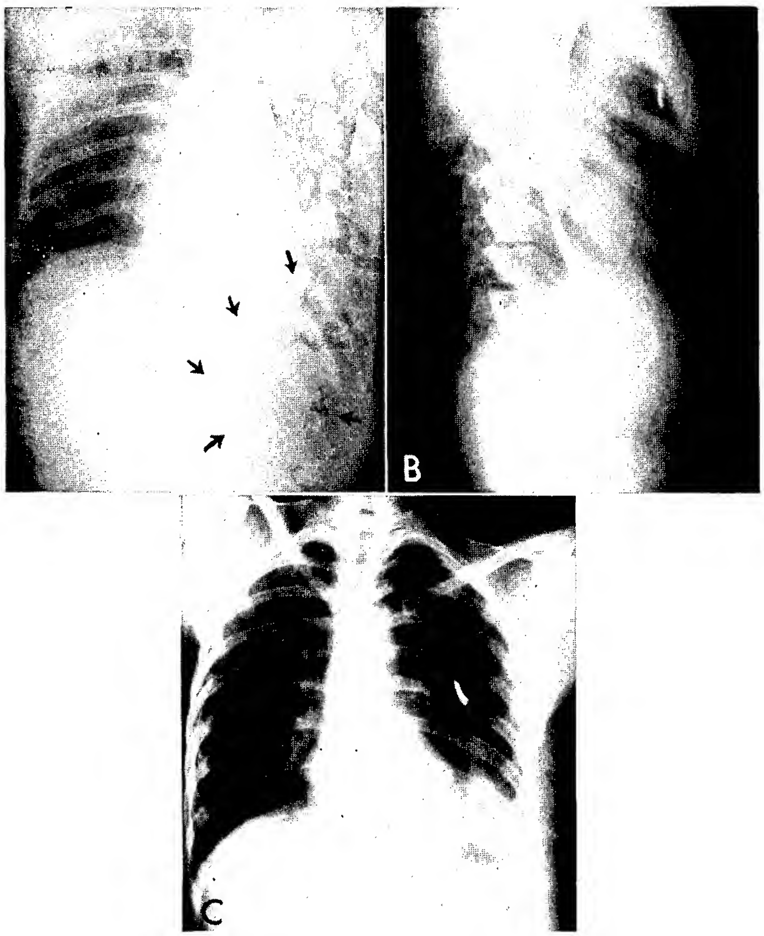

FIGURE 208 (case 7).—Serial roentgenograms in thoracoabdominal wound. A. Posteroanterior roentgenogram, 11 December 1944, immediately after wounding, showing massive opacity of left chest, haziness of right lung, and large amount of gas in stomach. B. Oblique roentgenogram after gastric decompression, with Levin tube still in stomach. A foreign body is now visible in left upper lung. Left chest is hazy. C. Posteroanterior roentgenogram on sixth postoperative day, showing expansion of left lung but somewhat hazy lung field. Retained shell fragment is clearly seen in left mid lung field.

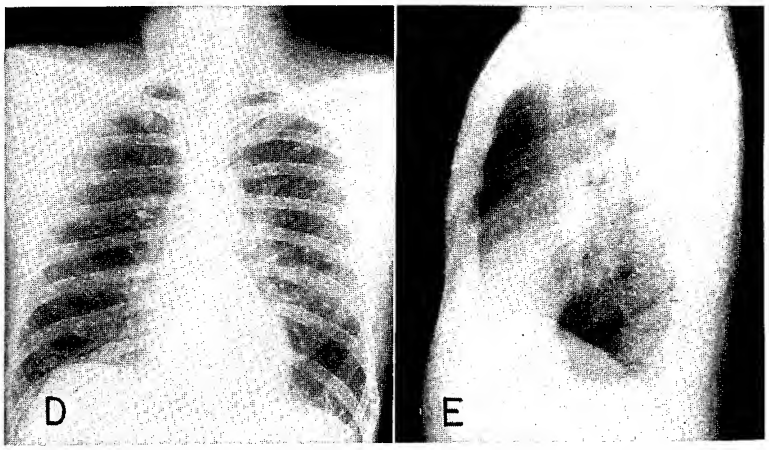

FIGURE 208.—Continued. D. Posteroanterior roentgenogram, 19 November 1960, almost 16 years after wounding, showing few adhesions along left diaphragm, healed fracture of eighth rib, and clear lung field. E. Lateral roentgenogram, on same date, showing clear lung fields and sharp costophrenic angles.

The right posterior wound did not extend through the muscle layers and did not involve the pleura, so it required only debridement. It was packed with fine-mesh gauze.

The patient received 1,000 cc. of blood during the operation, which he tolerated well. His temperature was elevated for the first 6 days, but otherwise his recovery was satisfactory. Roentgenologic examination (fig. 208C) on the sixth postoperative day showed the left lung to be well expanded.

The patient was evacuated to the 23d General Hospital at Vittel, France, on the seventh day after operation. Here an elective thoracotomy was performed, with removal of the foreign body in the left upper lobe.

Management in the Zone of Interior.—After satisfactory recovery from this operation, the patient was evacuated to the Zone of Interior. After hospitalization at Kennedy General Hospital, Memphis, Tenn., where he was found to require no further active treatment, he was sent to a reconditioning center on 28 July 1945. He was discharged shortly after V–J Day.

Followup.—A communication from the patient on 26 November 1960 stated that he was working as a carpenter's helper, was married, and had two children. He suffered from occasional attacks of nausea and vomiting, which responded to simple medication. He had no breathing difficulties except on strenuous exertion, when he became somewhat dyspneic.

Roentgenologic examination (fig. 208D and E) on 19 November 1960 showed the left lung to be well expanded. Two pleural streaks were seen at the left base in the posteroanterior view, but the costophrenic angles were sharp in the lateral film. The lung fields were normal except for prominence of the bronchovascular markings.

Comment.—This patient was admitted to a field hospital in serious condition, with a severe thoracoabdominal wound. He was in shock, which was complicated by both the wet lung syndrome and morphine poisoning, and resuscitation required 14 hours. At operation, it was found possible to save the damaged kidney. Since the foreign body in the left upper lobe could not be reached through the low thoracoabdominal incision being used, it was left in situ at the original operation and removed later at the base. The hematoma of the left lower lobe resolved spontaneously. Only reconditioning was needed in a Zone of Interior hospital.

At the present time, the patient is living an essentially normal life, with only occasional minor gastrointestinal symptoms and some dyspnea on strenuous exertion. His condition immediately after wounding was so precarious that the additional surgery necessary to remove the foreign body at the original operation might well have been fatal. Vigorous resuscitation, staging of surgery, and limitation of initial wound surgery were important factors in the successful result and in the patient's excellent state of health 16 years after wounding.

Case 8

Management overseas.—This 21-year-old infantryman sustained shell-fragment wounds of the left chest (fig. 209A), shoulder, upper arm, and the scalp at 1400 hours on 22 September 1944. He was given sulfonamide tablets and two units of plasma at the battalion aid station.

When he was admitted to the 11th Field Hospital at Plombières, France, shortly afterward, he was not in shock. The blood pressure was 130/80 mm. Hg, the pulse 80, and the respirations 36. He complained of severe pain in the chest and the abdomen.

Breath sounds were depressed on the left, apparently chiefly from pain; there was improvement when intercostal nerve block was done. Tenderness and rebound tenderness in the left upper quadrant, however, persisted, and peritoneal contamination had evidently occurred.

Roentgenologic examination of the chest (fig. 210A and B) showed the lungs to be comparatively clear. There was a small amount of fluid at the left base, and a small fragment in the left upper quadrant of the abdomen was seen on both posteroanterior and lateral films.

Resuscitation consisted, in addition to intercostal nerve block, of the slow administration of 500 cc. of blood and evacuation of the stomach through a Levin tube. No food had been taken that day, and there was little gastric content.

When the patient was taken to the operating tent at 1815 hours, the blood pressure was 90/50 mm. Hg and the pulse 114. Chest involvement was found to be minimal. The small 2-cm. wound of the eighth intercostal space (fig. 209A)

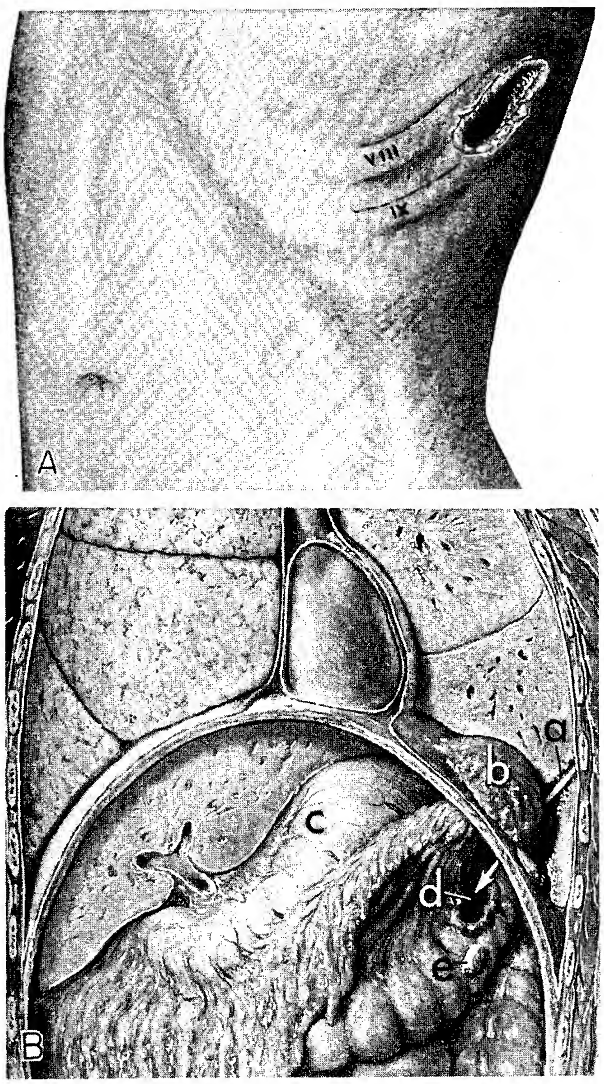

FIGURE 209 (case 8).—Schematic showing of thoracoabdominal wound. A. Small penetrating wound in left eighth intercostal space in midaxillary line. B. Pathologic findings: Laceration of lung (a), omentum plugging laceration of diaphragm (b), intact stomach (c), laceration of splenic flexure of colon (d), and foreign body (e).

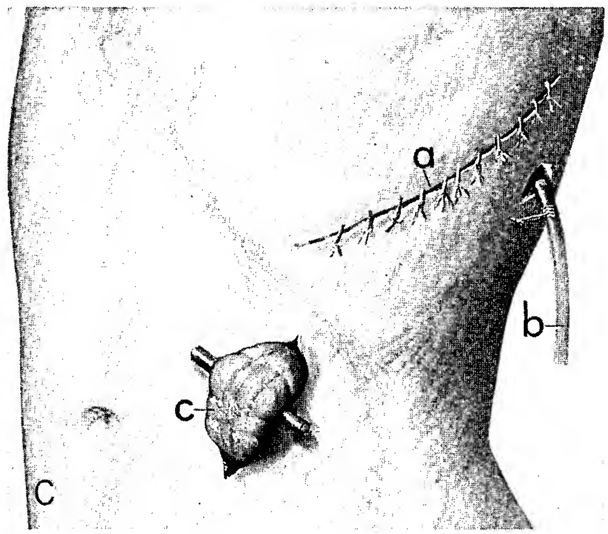

FIGURE 209.—Continued. C. Anterolateral chest wall at conclusion of operation: Closed thoracotomy incision (a), closed pleural drainage tube (b), and exteriorized loop of colon over glass rod (c).

could have been handled through either the chest or the abdomen, but the location of the foreign body indicated an approach through the thorax. After debridement of the chest wall, the incision was extended along the eighth intercostal space and the pleural cavity was opened. A moderate amount of bloody fluid was aspirated. The lower lobe of the left lung was lacerated (fig. 209B). A plug of omentum had herniated through a perforation in the diaphragm and sealed off the pleural cavity.

Excellent exposure of the upper abdomen (fig. 209B) was secured through an anterolateral incision in the diaphragm. The spleen and the stomach were intact. A 1-cm. laceration in the antimesenteric border of the transverse colon was repaired with fine silk sutures. Localized peritonitis was present in this area only. The foreign body seen on the roentgenograms (fig. 210A and B) was about 1 cm. in diameter and was adjacent to the colon. It was removed. The colon was exteriorized through a counterincision in the left upper quadrant and brought out over a glass rod. Exploration revealed no other injured organs.

The diaphragm was closed with interrupted silk sutures. Closed drainage was instituted in the ninth intercostal space posteriorly. The chest wall was closed tightly in layers (fig. 209C), primary closure being considered safe because of the small size of the wound.

The wounds of the shoulder, upper arm, and scalp were debrided.

The postoperative course was benign. The highest temperature was 100.8° F. The exteriorized loop of colon healed well, and gas was passed after the glass rod had been removed. The lungs remained clear throughout (fig. 210C).

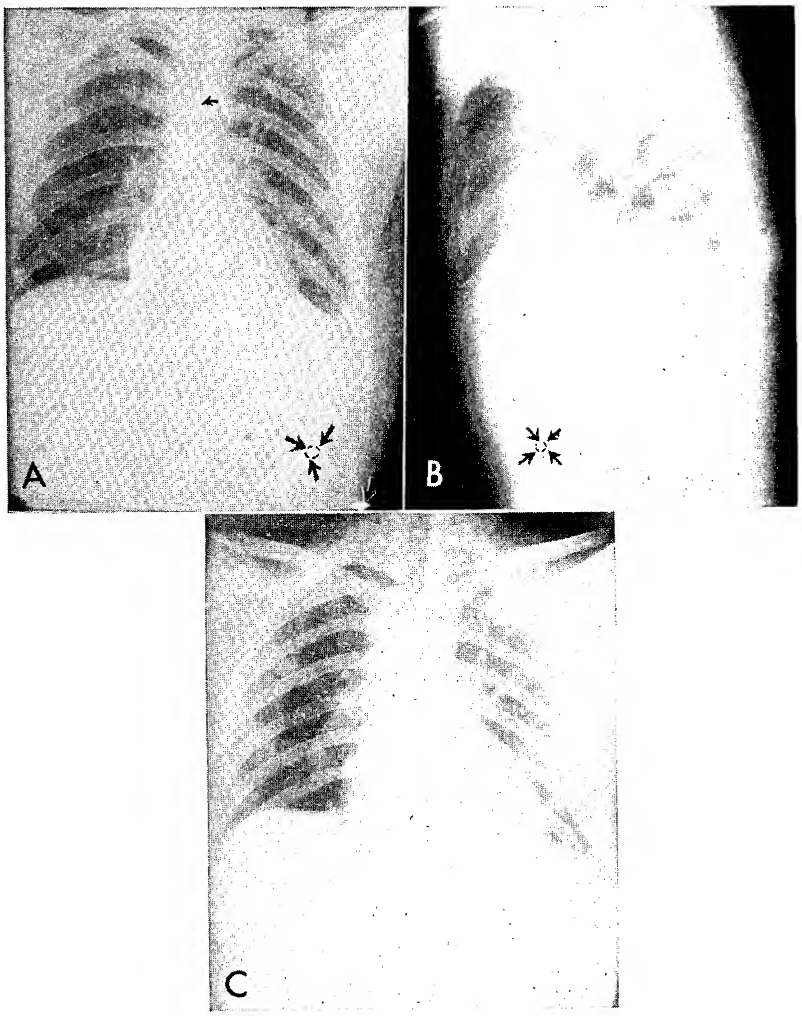

FIGURE 210 (case 8).—Serial roentgenograms in thoracoabdominal wound. A. Posteroanterior roentgenogram of chest, 22 September 1944, shortly after wounding, showing relatively clear lung fields, small amount of fluid in left pleural cavity, and small metallic foreign body in left upper quadrant of abdomen. Levin tube in esophagus is shown by arrow. B. Lateral roentgenogram on same date, showing small metallic foreign body in left upper quadrant of abdomen and haziness of lungs. Note that an artifact present in posteroanterior view is not seen in lateral view. C. Posteroanterior roentgenogram showing expansion of left lung on sixth postoperative day.

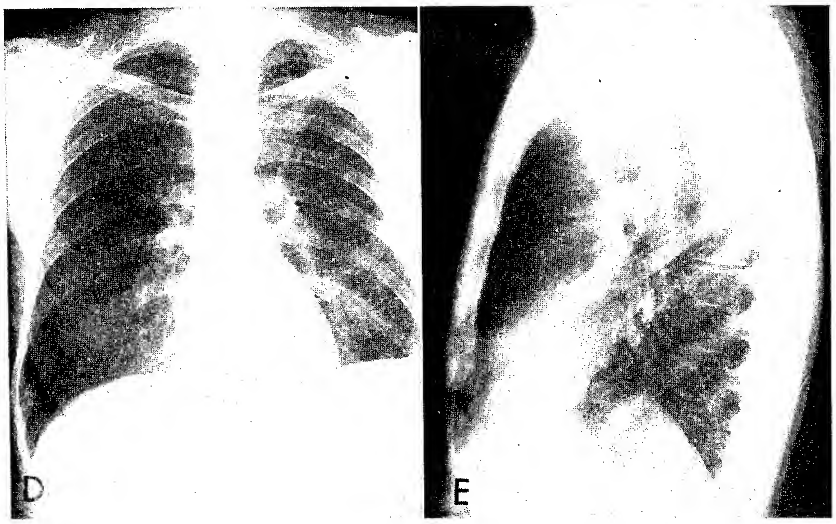

FIGURE 210.—Continued. D. Posteroanterior roentgenogram of chest, 14 February 1961, 16 years and 5 months after wounding, showing clear lung fields. Left diaphragm is flat and costophrenic sinus is blunted laterally. E. Lateral roentgenogram on same date, showing prominent bronchovascular markings, tenting of diaphragm anteriorly, and sharp posterior diaphragmatic sulcus.

The patient was evacuated to the 46th General Hospital on the 10th postoperative day. Here the loop colostomy was opened when some distention developed. It was closed shortly afterward.

Management in the Zone of Interior.—When the patient was evacuated to Battey General Hospital, Rome, Ga., on 29 December 1944, he required only rehabilitation. After a period of service on limited duty, he was discharged in August 1945.

Followup.—A communication from this patient on 14 February 1961 stated that he had worked as a truck driver since the war. He was married and had children. He had no digestive symptoms and no dyspnea and considered himself well except for occasional pain in the left chest. Roentgenograms at this time (fig. 210D and E) showed no abnormalities of consequence.

Comment.—This patient had a satisfactory recovery after severe thoracoabdominal wounds and multiple other injuries. Several reasons may be given: He was admitted to a field hospital 75 minutes after wounding. The gastrointestinal tract was almost empty, since he had taken no food that day. Minimal contamination occurred because of the prompt handling of the lacerations of the lung, diaphragm, and colon. The pleura was spared serious contamination because the omentum partly blocked off the wound of the colon and also plugged the diaphragmatic wound. Had the war continued, this man could have gone back to full duty. He is well at this time, more than 16 years after wounding, and is leading an active civilian life.

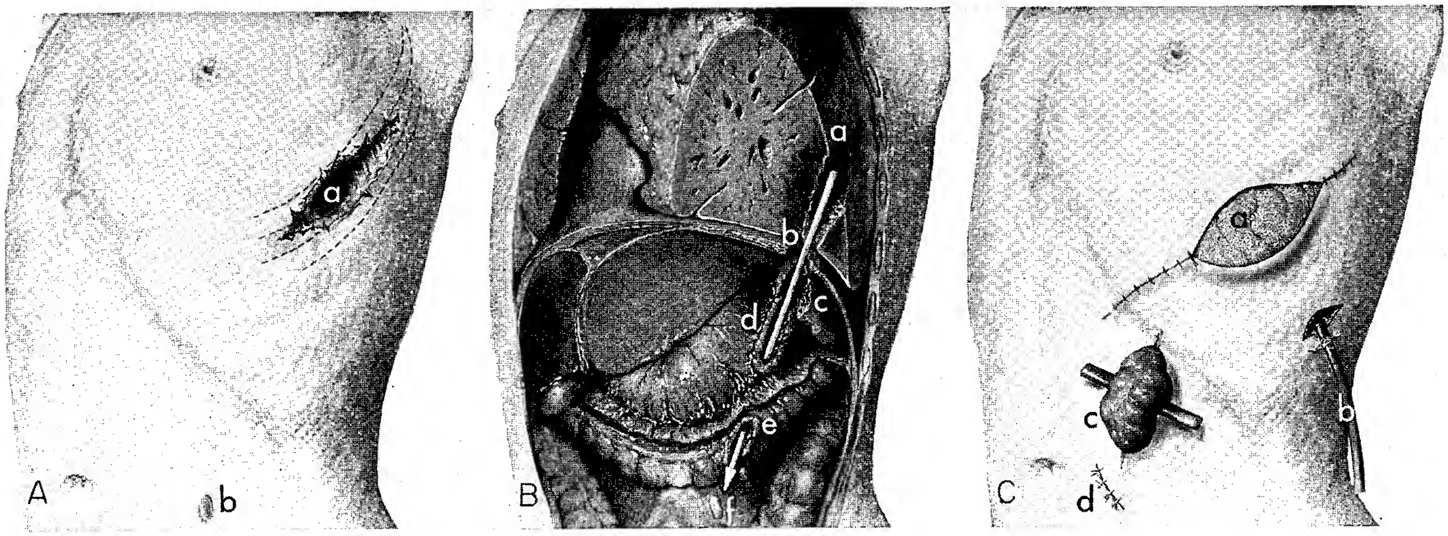

FIGURE 211 (case 9).—Schematic showing of thoracoabdominal wound. A. Lateral aspect of chest and abdomen showing 8-cm. sucking wound of sixth intercostal space (a) and foreign body in abdominal wall (b). B. Pathologic findings: Laceration of left lower lobe of lung (a), laceration of diaphragm (b), laceration of spleen (c), laceration of stomach (d), laceration of colon (e), and small foreign body in abdomen (f). C. Anterolateral aspect of left chest and abdomen at conclusion of operation: Central portion of chest wound packed with fine-mesh gauze (a), closed intrapleural drainage tube (b), exteriorized colon (c), and counterincision for removal of foreign body in abdominal wall (d).

Case 9

Management overseas.—This 21-year-old infantryman sustained a high explosive shell-fragment wound of the left chest at 1625 hours on 30 October 1944 in the mountains of northern France. At the battalion aid station, the sucking wound was packed (fig. 211A), and he was given morphine gr. ¼.

When he was admitted to the 11th Field Hospital at Eloyes at 1825 hours, he was in shock, with a blood pressure of 80/50 mm. Hg. He complained of severe chest and abdominal pain and was spitting up blood. Breath sounds were absent on the left. The right chest was clear. Tenderness, spasm, and rebound tenderness were present in the left upper quadrant of the abdomen. Roentgenograms are shown in figure 212. The right chest was fairly clear, and the cardiac shadow was not enlarged. A small foreign body was discerned in the region of the left upper quadrant of the abdomen. On further examination (fig. 212A and B), it was seen that two foreign bodies were present, one deep in the left upper quadrant and the other apparently in the abdominal wall. Roentgenogram (fig. 212C) showed haziness over the left chest.

Two units of plasma were given as soon as the patient was admitted, and transfusions of 1,500 cc. of blood were given over the next 3 hours. By the end of this time, the blood pressure was stabilized. Since there was no improvement in the abdominal symptoms and signs, the patient was taken to the operating room at 2125 hours.

The sucking wound in the sixth intercostal space was debrided, and the incision was extended in this interspace down to the costal margin. The left lower lobe of the lung was lacerated (fig. 211B) and was the site of a small hematoma. The diaphragm, which was torn, was opened at the dome anterolaterally. This provided excellent exposure of the upper abdomen. The spleen, which was badly torn, was bleeding and was removed. Two perforations in the stomach were repaired easily, as was a through-and-through wound of the splenic flexure of the left colon. A small foreign body was found in this region, and a larger object, palpated in the anterior abdominal wall, was removed through a counterincision. The splenic flexure of the colon was mobilized, the perforations in it closed, and the involved area brought out through a stab wound in the left upper quadrant of the abdomen, over a glass rod.

The diaphragm was repaired with interrupted No. 00 silk sutures. Closed pleural drainage was instituted in the eighth intercostal space; the catheter was connected to a closed system. After the pleural cavity had been thoroughly lavaged with physiologic salt solution, the chest wall was closed in layers. The central portion of the wound was left open (fig. 211C) and was packed with fine-mesh gauze down to the muscle layer.

For the first week after operation, the temperature rose daily to 101° F. Peristalsis was observed on the second day. The colostomy was opened, and fluids by mouth were permitted. The lung expanded well and there was only a moderate pleural reaction when the patient was evacuated to the 23d General

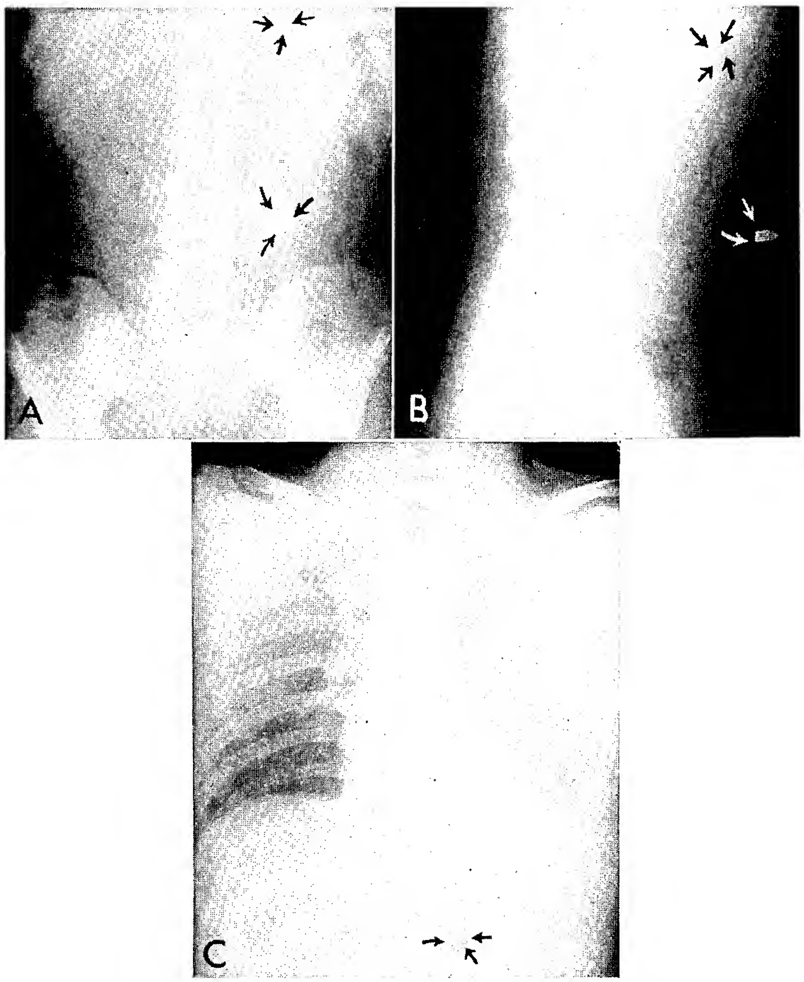

FIGURE 212 (case 9).—Serial roentgenograms in thoracoabdominal wound. A. Anteroposterior roentgenogram of abdomen showing two intra-abdominal foreign bodies. B. Lateral roentgenogram of chest and abdomen on same date, showing two metallic foreign bodies in left upper quadrant. C. Posteroanterior roentgenogram of chest, 30 October 1944, immediately after wounding, showing haziness of left hemothorax, diffuse pleural fluid, and small metallic foreign body in left upper quadrant. Right lung is fairly clear.

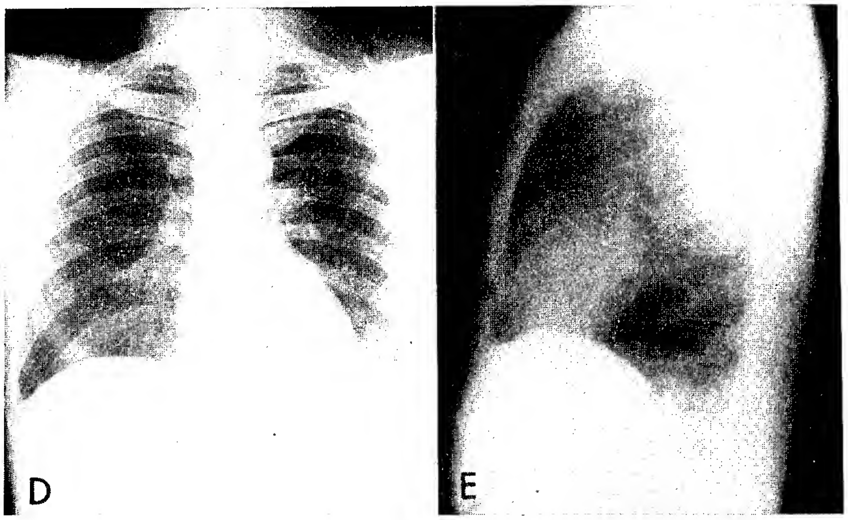

FIGURE 212.—Continued. D. Posteroanterior roentgenogram, 29 December 1960, 16 years after wounding, showing flat left diaphragm and relatively clear lung fields. E. Lateral roentgenogram on same date, showing sharp costophrenic angles.

Hospital, Vittel, France, on the 10th day. He had, however, complained of some pain and distention in the left upper quadrant. Later, swelling, tenderness in the left costal margin, and fever indicated the development of a subphrenic abscess, which was drained successfully on 30 November 1944.

Management in the Zone of Interior.—The patient was evacuated to Barnes General Hospital, Vancouver, Wash., on 29 December 1944. The colostomy, which functioned well, was closed in April 1945. He received a disability discharge on 11 August 1945.

Followup.—On 28 December 1960, the patient reported that he had worked as a printer since his discharge from the army. He was married and had six children. He had no digestive or other complaints and considered himself well. Roentgenograms made on 29 December 1960 (fig. 212D and E) revealed clear lung fields, with prominent bronchovascular markings.

Comment.—This was a patient with an extremely severe thoracoabdominal wound, which was treated promptly, though before his admission to the field hospital, spillage of contents into the upper abdomen from wounds of the stomach and colon had produced severe shock. Prompt surgery was lifesaving in this case. Colostomy prevented further contamination of the upper abdomen. The subphrenic abscess which developed was promptly drained at the base section hospital, and healing was satisfactory. The colostomy was closed without difficulty in a Zone of Interior hospital. Although the chest trauma in this case was moderately severe, the wound could perhaps have been handled from below. Exposure, however, would have been more difficult, and it was

thought better to handle the sucking wound of the chest and the wound of the diaphragm in a single operation. The excellent health of the patient 16 years after operation points up the value of the staged treatment that he received.

HEMATOMA

The diagnosis of intrapulmonary hemorrhage or hematoma was made in forward hospitals in 89 cases in this series. When the chest was not opened and only a debridement of the chest wall was done, the diagnosis was made on clinical grounds. When pneumonitis and atelectasis could be ruled out, the presence of hemoptysis and a pulmonary parenchymal shadow, with slow resolution of the shadow, was regarded as confirmation of the diagnosis.

Hematoma of the lung is a pathologic process in which there is extravasation of blood into the alveoli and interalveolar tissue of the pulmonary parenchyma. Observations at base section hospitals in the communications zone showed that these lesions resolved slowly within 4 to 6 weeks, according to their severity. No mention is made of their persistence in any of the roentgenologic reports in this series at Zone of Interior hospitals from 2 to 5 months or longer after wounding.

In other words, all 89 hematomas resolved spontaneously and without morbidity. No resection of any type was performed for them, nor did lung abscess or other secondary infection develop in any instance, even when a massive hematoma of an entire lobe might liquefy to produce a cystlike shadow on the roentgenogram.

The evidence from these 89 cases thus clearly indicates that there is no reason to perform lobectomy or segmental resection of a lung that at initial wound surgery is tense and boggy and contains large amounts of extravasated blood. As alarming as such a lung may appear to a surgeon who is viewing his first pulmonary hematoma, there should be no surgical interference. The lung has tremendous recuperative power because of its dual blood supply from the bronchial and pulmonary arteries, and recovery can be expected without complications when this natural power is supplemented by vigorous measures to keep the bronchial tree clear of blood and mucus and the pleural cavity dry.

The concept of noninterference in pulmonary hematoma formation is one of the important advances in thoracic surgery developed in World War II.

Case 10

Management overseas.—This 31-year-old infantryman was wounded by a fragment of a 20-mm. missile from a German airplane at 1500 hours on 24 April 1945, at Amerbach, Germany. After a delay of 25 minutes, the ensuing sucking wound was packed with petrolatum-impregnated gauze at a battalion aid station, and sulfonamide crystals were placed in the wound.

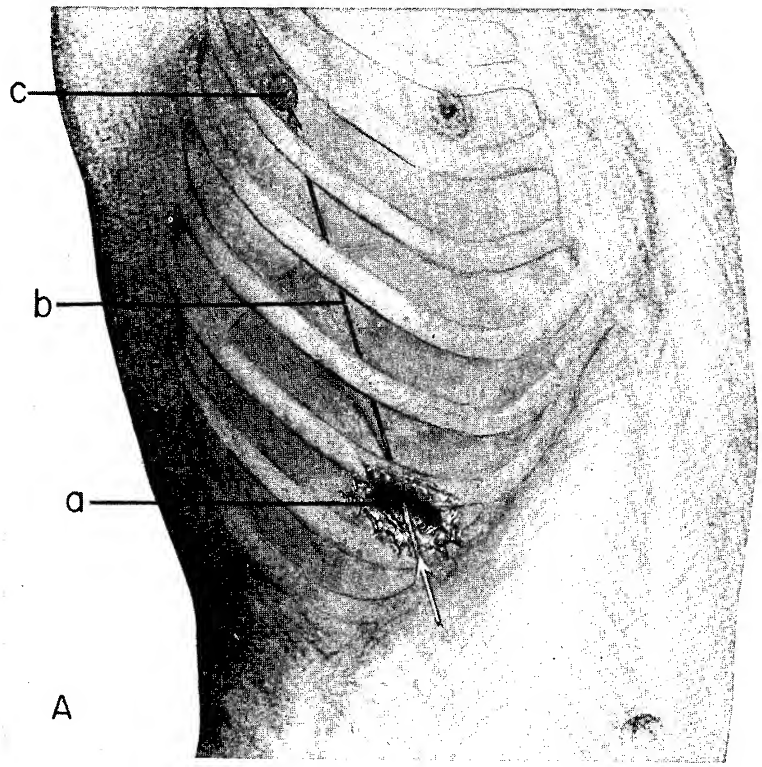

FIGURE 213 (case 10).—Schematic showing of thoracic wound with massive hematoma of the right lung. A. Course of missile: Anterolateral wound of entrance in eighth right intercostal space, with resulting sucking wound (a), passage of missile through lung to lodge close to mediastinum posteriorly (b), and high explosive shell fragment (c). Location of the wound introduced the possibility of diaphragmatic laceration.

When he was admitted to the 66th Field Hospital at Gunzenhausen, Germany, at 1855 hours, he was cyanotic and dyspneic, and his respirations were wet and labored and were 40 to the minute. The blood pressure was 150/72 mm. Hg and the pulse 120.

Examination revealed a large anterolateral sucking wound of the eighth intercostal space (fig. 213A), packed with an airtight dressing. There were signs of fluid and air in the right chest (fig. 214A and B), and numerous wet rales over both lung fields, but no cardiac shift.

Resuscitation occupied 16 hours. It consisted of the administration of oxygen; the immediate slow administration of 500 cc. of blood and the deferred, very slow, administration of 1,000 cc. of blood; evacuation of the pleural cavity by loosening the gauze packing and tipping the patient so that the wound drained about 500 cc. of blood; intercostal nerve block (T_4–T_8); and bronchial

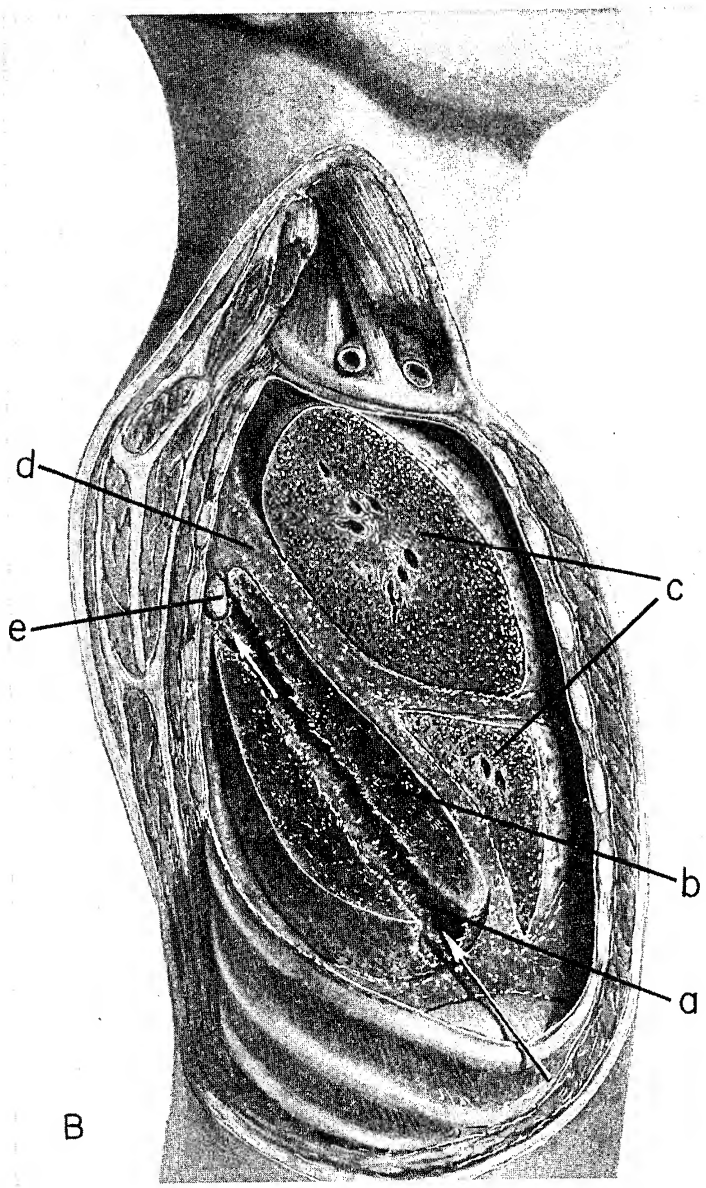

FIGURE 213.—Continued. B. Findings at thoracotomy: Laceration of right lower lobe of lung (a), with massive hematoma of entire lobe (b), wet lung of adjacent lobes (c), clots (500 cc.) and blood (300 cc.) in right pleural cavity (d), and foreign body resting in right lower lobe and pleural cavity (e).

aspiration per catheter. The patient coughed voluntarily after the nerve block and the catheter aspiration, and the lung gradually cleared of rales.

The wound in the right thoracic wall was thoroughly debrided under endotracheal anesthesia. Fragments of the fractured eighth rib were resected and the incision was extended in the intercostal space to make a formal thoracotomy (fig. 213B). The diaphragm was found intact. The right lower lobe of the right lung was lacerated and was the site of a massive hematoma which resembled the liver in appearance. A foreign body free in the posterior pleural cavity (fig. 214B) was removed, and 500 cc. of blood clot and 300 cc. of fluid blood were evacuated.

Although the lung was lacerated, it was not blowing air, and no attempt was made to place sutures in the boggy, engorged right lower lobe.

At this point, it is typical of conditions under which much war surgery was done in the Mediterranean theater that a small bug flew into the pleural space. It was not seen again, but the cavity was thoroughly lavaged with 1,500 cc. of physiologic salt solution.

The muscles were closed in layers with interrupted sutures of fine silk. The posterior wound of entry was left open and was packed with fine-mesh gauze down to the muscle layer. Closed intrapleural drainage was instituted in the eighth intercostal space posteriorly. Penicillin (500,000 units) was injected into the tube, which was clamped off for 3 hours.

Bronchoscopy immediately after operation produced a large amount of blood and mucus from the right main bronchus and the right lower lobe bronchus.

The patient ran a febrile course (101°–102° F.) for the first 5 days, after which his temperature gradually dropped to 99° F. Intercostal nerve block was repeated twice, with relief of pain and effective cough. Roentgenograms on the third postoperative day (fig. 214C) showed a small cyst with a fluid level, the result of liquefaction of the hematoma in the right lower lobe of the lung.

The patient was evacuated to a base hospital on the eighth postoperative day and thence to the Zone of Interior.

Management in the Zone of Interior.—When the patient was received at Walter Reed General Hospital 2 months after wounding, his only complaint was pain in the right chest, with intercostal neuritis. Roentgenograms were essentially negative. He was returned to duty in the Zone of Interior but eventually was discharged for disability.

Followup.—The patient now works as a manager of a store, with no apparent disability.

Roentgenograms 15 years and 10 months after wounding (fig. 214D and E) showed clear lung fields and no evidence of the massive hematoma or the cyst with fluid level seen shortly after wounding.

Comment.—The problems in this case were (1) a sucking wound, (2) a massive hematoma of the right lower lobe of the lung, (3) a foreign body in the pleura, and (4) the wet lung syndrome. Significant factors in the history are

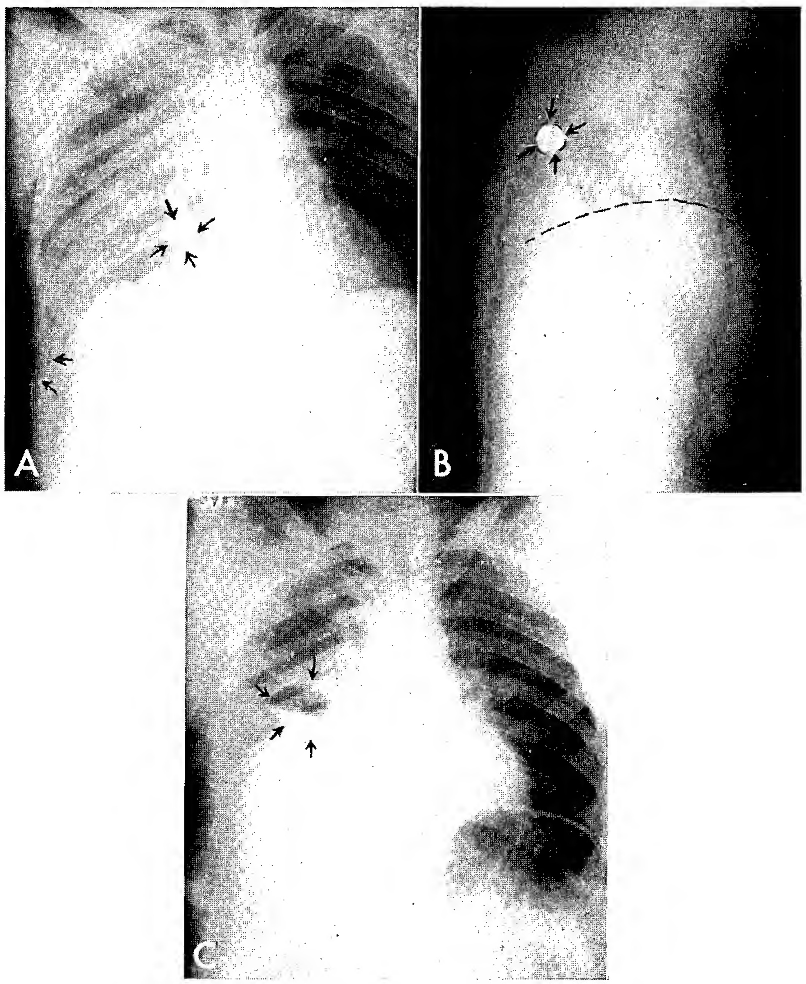

FIGURE 214 (case 10).—Serial roentgenograms of hematoma of right lower lobe of lung. A. Posteroanterior roentgenogram, 24 April 1945, immediately after wounding, showing fracture of eighth rib at diaphragm and foreign body in right lower lung close to hilus. Note haziness of right lung field and shift of heart to left. B. Lateral roentgenogram on same date, showing foreign body lying posteriorly in pleural cavity. C. Posteroanterior roentgenogram on 27 April 1945 (third postoperative day) showing cyst with fluid level, result of liquefaction of hematoma of right lower lobe.

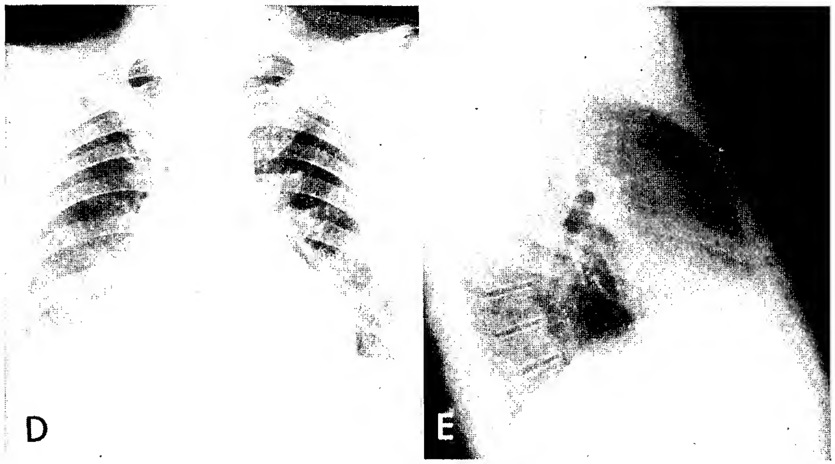

FIGURE 214.—Continued. D. Posteroanterior roentgenogram of chest, 2 February 1961, 15 years and 10 months after wounding, showing complete absorption of massive hematoma of right lower pulmonary lobe. There is no evidence of cyst with fluid level seen in April 1945. The diaphragmatic shadows are flattened laterally. E. Lateral roentgenogram on same date, showing flattened diaphragms anteriorly and fairly deep sulci posteriorly. Lung fields are clear.

the 16-hour preoperative preparation, the delay being caused by the wet lung syndrome; the necessity for traumatic thoracotomy because of the sucking wound, with removal of the readily accessible intrapleural foreign body; and the conservative management of the massive hematoma of the right lower lobe. Although the hematoma eventually liquefied and formed a pseudocyst, there are no apparent residua and the lung fields are essentially clear more than 15 years after injury.

In this case, the performance of lobectomy at initial wound surgery to correct the hematoma might have been more than this dangerously wounded casualty could have endured. His course since wounding indicates that the surgery was not necessary.

WET LUNG

Since the concepts and management of traumatic wet lung were developed in the Mediterranean theater (p. 208), it is important to assess the results of the incidence and management of this complication of thoracic injuries. It was extremely troublesome in forward hospitals, in which initial surgery was performed. It was a major problem in 65 of the 167 cases in this series.

In general, it was the policy to treat these casualties intensively in forward hospitals (p. 217) and not attempt to exacuate them, rgeardless of the nature of their wounds, until their lungs were comparatively dry. As a matter of fact, they withstood transportation very poorly. It was therefore the policy to

retain them at the primary installation to which they were admitted unless, as sometimes happened, the tactical situation required the evacuation of the whole hospital. At the Battle of the Bulge, at Christmas 1944, the Seventh U.S. Army was serving as the southern anchor of the front, and as a precautionary measure, all noncombat personnel were evacuated from the frontlines. The clearing station which had been supported by a platoon of the 66th Field Hospital was moved 6 miles to the rear, but the platoon itself could not move for another week because it was holding nontransportable casualties who had undergone thoracotomy or thoracolaparotomy and who could not be moved because of serious wet lung complications.

When wet lung was properly managed in forward hospitals, few complications arising from it were encountered in base hospitals. When the reverse was true, complications were numerous. In this series, only two patients showed a late pneumonitis which might have been connected with the original wet lung syndrome. This low incidence is in sharp contrast to the earlier experience: In three of the four deaths in this series, already described (p. 450), the wet lung syndrome had been a major problem in the resuscitative regimen, and in the patient with a spinal cord injury, the problem was never completely solved. This patient, who had multiple wounds, was, however, the only one in the group in whom the wet lung factor was an important cause of death.

By the time casualties reached the Zone of Interior, there was never any clinical problem traced to the orginal wet lung syndrome if it had been properly handled in the forward hospital. Chronic pneumonitis, bronchitis, and bronchiectasis were seldom recorded—never in this series—nor was the massive atelectasis so frequent in World War I casualties seen in the thoracic casualties of World War II. This, no doubt, reflects the careful attention paid in forward installations to the correction of the wet lung.

The following case report illustrates various aspects of this condition.

Case 11

Management overseas.—A 32-year-old infantry major was wounded in the left chest by a shell fragment on 22 January 1944, while he was crossing the Rapido River during the assault on Cassino. He took the sulfonamide tablets in his own first aid kit, and the corpsman applied a pressure dressing and gave him a unit of plasma. Thirty minutes later, he was given morphine gr. ½ in a battalion aid station, for severe chest pain.

When the casualty arrived at the 11th Field Hospital in Mignano Monte Lungo, Italy, at 1615 hours, the wound (fig. 215A) was bleeding externally and he had been coughing up blood. He was extremely dyspneic and was disoriented and in shock, with a blood pressure of 55/35 mm. Hg. The pulse, which was difficult to count, was 130, and the respirations 40. Immediate resuscitative measures consisted of the administration of nasal oxygen; the administration of three units of plasma and 500 cc. of blood; repacking of the

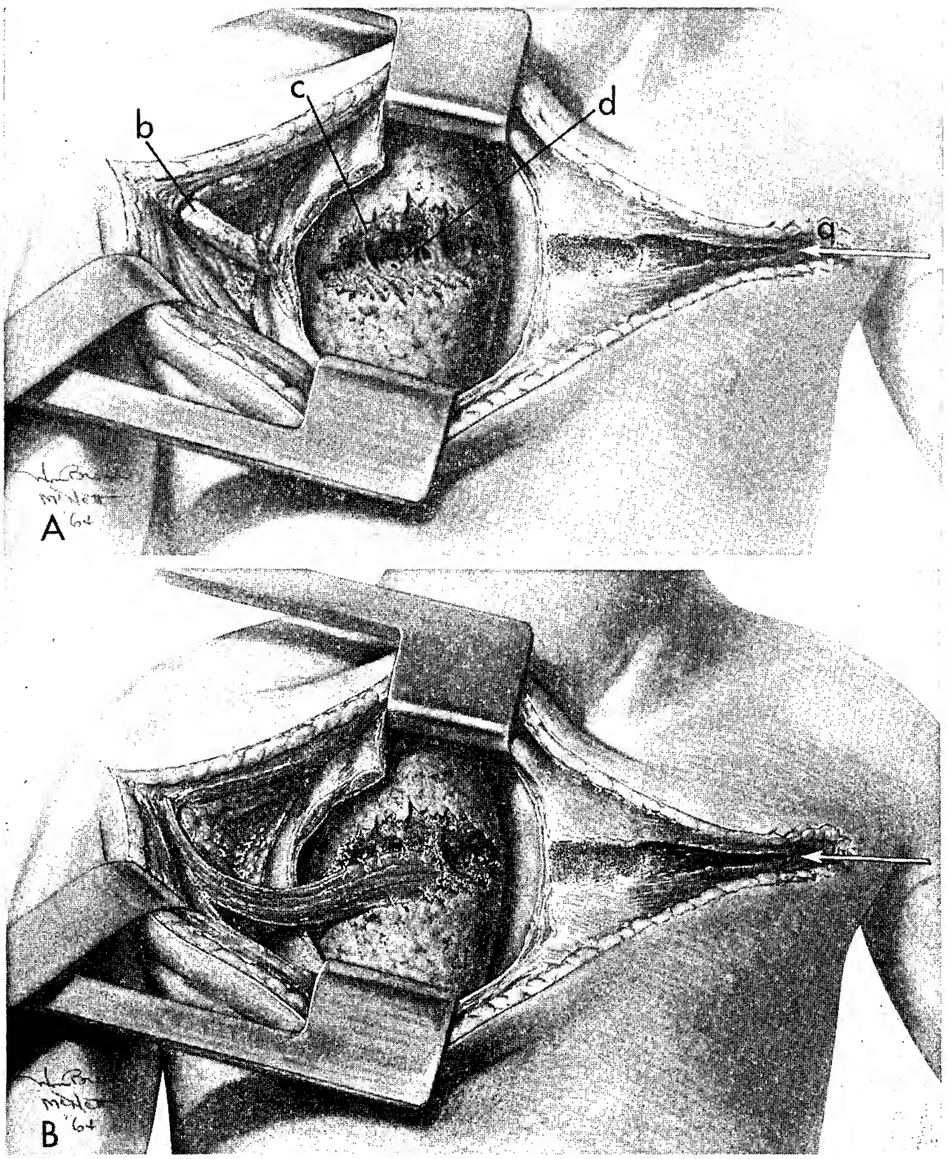

FIGURE 215 (case 11).—Schematic showing of large sucking wound of chest. A. Wound after debridement of chest wall: Wound of entrance in left chest (a), large shell fragment in right pleura and axilla (b), laceration of right upper lobe of lung (c), and open apical segmental bronchus (d). B. Technique of bronchial closure. Blowing segmental bronchus sutured with fine silk and reinforced with pedicle muscle graft.

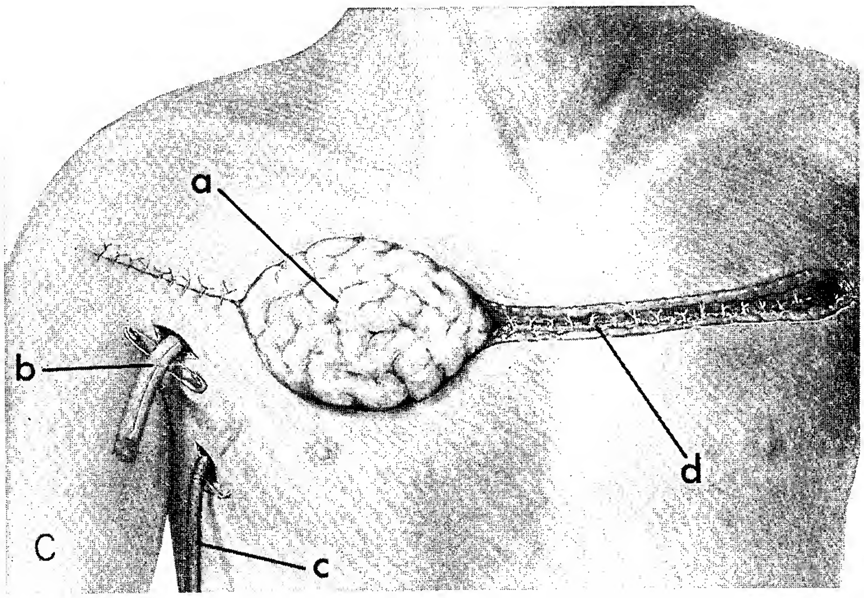

FIGURE 215.—Continued. C. Appearance of wound at end of operation: Gauze pack in chest wall and lung (a), Penrose sheath drain in right axilla (b), closed pleural drainage (c), and closure of muscles to superficial fascia (d).

wound, which was oozing and sucking, with petrolatum-impregnated gauze, repeated bronchial suction, with aspiration of blood and mucus, as bubbly rales continued present over both lungs; and the very slow administration of another 500 cc. of blood.

Roentgenograms (fig. 216A) showed a large foreign body (4 by 2 cm.) in the right pleura and axilla and haziness of both lung fields, more marked on the right. There was no mediastinal shift.

Traumatic thoracotomy was performed 10 hours after resuscitation had been begun. The wound was debrided across the sternum, after which the shattered second and third costal cartilages were resected, with portions of the second and third ribs on the right (fig. 215B). The wound was thoroughly debrided, and the foreign body in the pleura and right axilla was removed. The lung was partly adherent near the apex and badly torn below. Lobectomy would have been necessary to close it completely. The fistula in the apical segmental bronchus was closed with silk, and the closure was reinforced with a graft of pectoralis minor.

The wound in the lung, pleura, and chest wall was packed tightly with fine-mesh gauze (fig. 215C) over an area 4 by 6 centimeters. The remainder of the wound and the muscles were pulled together with interrupted sutures but left open from the fascial layer outward.

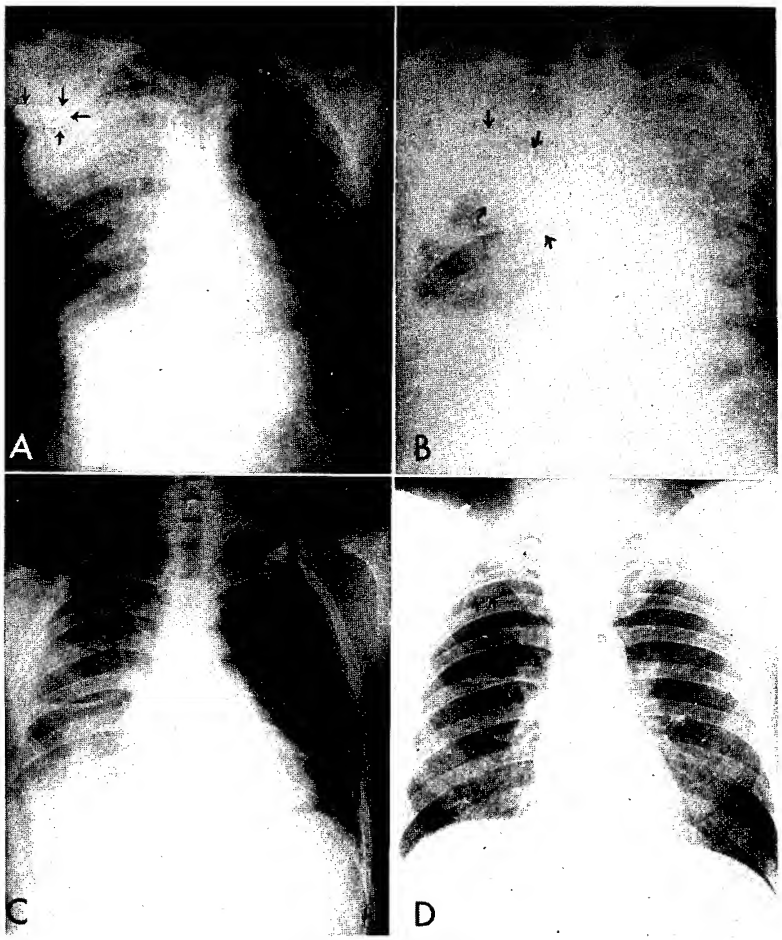

FIGURE 216 (case 11).—Serial roentgenograms of sucking wound of chest with wet lung syndrome. A. Posteroanterior roentgenogram, 22 January 1944, immediately after wounding, showing large foreign body in right axilla and pleura, with diffuse haziness of both lungs, more marked on right. B. Posteroanterior roentgenogram first postoperative day, showing severe bilateral pulmonary edema. Note gauze pack in right mid lung field. C. Posteroanterior roentgenogram, 7 February 1944, showing clearing of lungs. Dotted line outlines site and extent of gauze pack; 1-cm. right lateral pleural shadow indicates loculated pleural fluid. D. Posteroanterior roentgenogram, 3 May 1960, 16 years after wounding, showing essentially clear lung fields. Note anterior stumps of second and third right ribs.

A Penrose drain was left in the left axilla, and closed pleural drainage was instituted. Bronchoscopy immediately after operation produced a large amount of bloody mucus, chiefly from the right upper lobe.

The postoperative course was extremely stormy because of pulmonary edema. Roentgenograms made the day after operation (fig. 216B) showed massive edema of both lungs, with the pack in the right anterior chest wall and the lung. Treatment consisted of nasal oxygen, supplemented by brief periods of positive pressure oxygen, administered with each voluntary inspiration by means of an anesthetic machine and manual pressure on the bag (fig. 50, p. 162); intercostal nerve block; and repeated bronchial suction. Because of some blowing from the wound, which did not end until a week after operation, it was necessary to repack portions of the chest wall. Thoracentesis was done twice after closed drainage was terminated; about 1,000 cc. of bloody fluid was aspirated each time.

When the patient was evacuated on the 14th postoperative day, the cavity in the lung had decreased to about the size of an egg and was granulating well, and the right had expanded (fig. 216C).

At the 36th Evacuation Hospital, which was then operating as a forward thoracic surgery center, Maj. Thomas H. Burford, MC, performed a fat graft of the pulmonary cavity with delayed primary closure of the large anterior wound.

Followup.—This patient required no active treatment in the Zone of Interior, where he was eventually given a disability discharge. Since that time, he has been working as a rural mail carrier and has been followed by a private physician. Roentgenograms made on 3 May 1960 (fig. 216D) showed the resected ends of the second and third ribs on the right. Vascular markings in the lung fields were prominent, but the fields were essentially clear.

Comment.—This patient had a very large sucking wound, complicated by a wet lung syndrome of such severity that he was delirious from hypoxia for the first 4 days after wounding. The lacerated upper lobe of the right lung was not sacrificed; a muscle graft closed the major bronchial fistula, and packing of the lung and the chest wall was a successful complementary procedure. Right upper lobe lobectomy would never have been feasible in this patient until he reached the base hospital, and there, a skillfully performed fat graft and delayed primary wound closure made further surgery unnecessary. The wet lung syndrome and massive bilateral pulmonary edema made his early care extremely difficult.

HEMOTHORAX

Hemothorax is the most common complication of thoracic wounds, which might be expected, since in every penetrating wound of the chest in which the pleural space is involved there is some degree of extravasation of blood into the cavity. A small amount of blood is of little clinical significance if infection

does not occur; it is well tolerated by the pleura, and absorption is the rule. If larger amounts are present, preoperative aspiration is necessary to expand the lung and increase the vital capacity, as well as to supply an accurate index of the amount of hemorrhage which has occurred into the pleural space. After operation, the cavity must be kept empty by the use of intercostal closed drainage and repeated thoracenteses.

In World War II, when these principles were employed, the goal was to evacuate the casualty to the base section with the pleural cavity completely dry. This was not always possible. In spite of diligent aspiration of blood from the chest, a lung which has been traumatized and collapsed temporarily loses its elastic recoil and its ability to expand. During the period in which it is regaining its elasticity, a pleural effusion develops and there is a deposit of fibrin that forms a pleural membrane. This membrane is often quite inelastic, and in some cases, the process includes massive clotting, which can be handled only by decortication.

In this series of 167 chest wounds, bleeding into the pleural cavity was sufficiently persistent and of sufficient magnitude, in 91 instances, to create a considerable clinical problem. In 77 of these patients, repeated thoracenteses before operation, repeated after operation and supplemented by closed intercostal drainage, were successful in expanding the lung. Only 14 of the casualties were evacuated to the rear with persistent or clotted hemothorax and pulmonary collapse. These figures would seem to support the policy of repeated, prompt aspiration of the pleural cavity in hemothoraces.

At the base, decortication was carried out in nine cases, seven times for organizing hemothorax and twice for hemothoracic empyema. The other seven casualties who developed empyema were treated by drainage. This means that decortication was necessary in only 10 percent of the patients in this series with severe hemothorax and in only about 5.3 percent of the total series. No patient who underwent decortication on any indication was returned to duty overseas.

In the Zone of Interior, 2 of the 91 patients with persistent hemothorax developed late empyemas which had to be drained. No additional decortications were necessary. There were no deaths in this group of patients and no major disabilities due either to chronic empyema or to major collapse of a so-called captive lung. No patient had a chronic draining sinus of the chest wall.

These results are in sharp contrast to the results in World War I, after which the thoracic wards in Veterans' Administration hospitals were full of patients with collapsed lungs, chronic empyemas, and persistent sinuses of the chest wall following hemothorax and hemothoracic empyema. The excellent results in the World War II patients, of which the results in this series are typical, were attributable not only to adherence to the principles established for forward surgery but also to the proper timing and staging of surgery in base hospitals before the casualties were transferred to the Zone of Interior.

Case 12

Management overseas.—This 23-year-old infantry sergeant received a shell-fragment wound of the posterior left chest at 1400 hours on 21 September 1944, at Remiremont, France. He also received a wound of the scalp. Immediate treatment consisted of a pressure dressing, on which sulfanilamide powder had been sprinkled, and the subcutaneous administration of morphine gr. ½. A unit of plasma was given later at a clearing station.

When the patient was admitted to the 11th Field Hospital at Plombières at 1710 hours, he was comatose and in shock, with wet respirations and pinpoint pupils. The blood pressure was 90/40 mm. Hg, the pulse very rapid and difficult to count, and the respirations 14. Although the record did not indicate it, further inquiry produced the information that another half grain of morphine had been administered at the battalion aid station.

The patient was obviously in morphine poisoning. Shortly after he was admitted to the hospital, the blood pressure began to drop further, and he was given a unit of plasma and 500 cc. of blood. An intratracheal catheter was introduced, and repeated aspirations were carried out; oxygen was administered through the catheter between the aspirations. When the respirations fell to 12, three ampules of Coramine (nikethamide) were administered intravenously. When the sucking wound of the left chest (fig. 217A) was inspected, a small amount of blood drained from it.

At 1900 hours, the patient coughed out the catheter, after which he coughed up bloody mucus voluntarily. Oxygen was administered by nasal catheter. When thoracentesis of the left chest was done posteriorly, only 5 cc. of blood and 20 cc. of air were aspirated; there was no evidence of tension pneumothorax. Penicillin was given intramuscularly.

In spite of the active therapy carried out, the lungs remained wet. Over the next 18 hours, however, there was gradual improvement, in spite of evidence, by the results of thoracentesis, of continued hemorrhage into the left chest. Over this period, treatment consisted of two additional blood transfusions, intercostal nerve block, and the administration of oxygen by positive pressure.

At 1400 hours on 22 September 1943, the patient was considered sufficiently prepared to withstand surgery, which was performed under endotracheal anesthesia, in the right posterolateral position. The wound of the scalp was debrided, together with the extensive wound of the left chest and the back. The large wound over the left scapula (fig. 217B) was found to connect with the right shoulder. On the left side, there were extensive lacerations of the trapezius, latissimus dorsi, subscapularis, and rhomboid muscles. A large part of the central portion of the left scapula was destroyed. The involved area was debrided, which left a portion of the tip in situ, together with the intact upper portion.

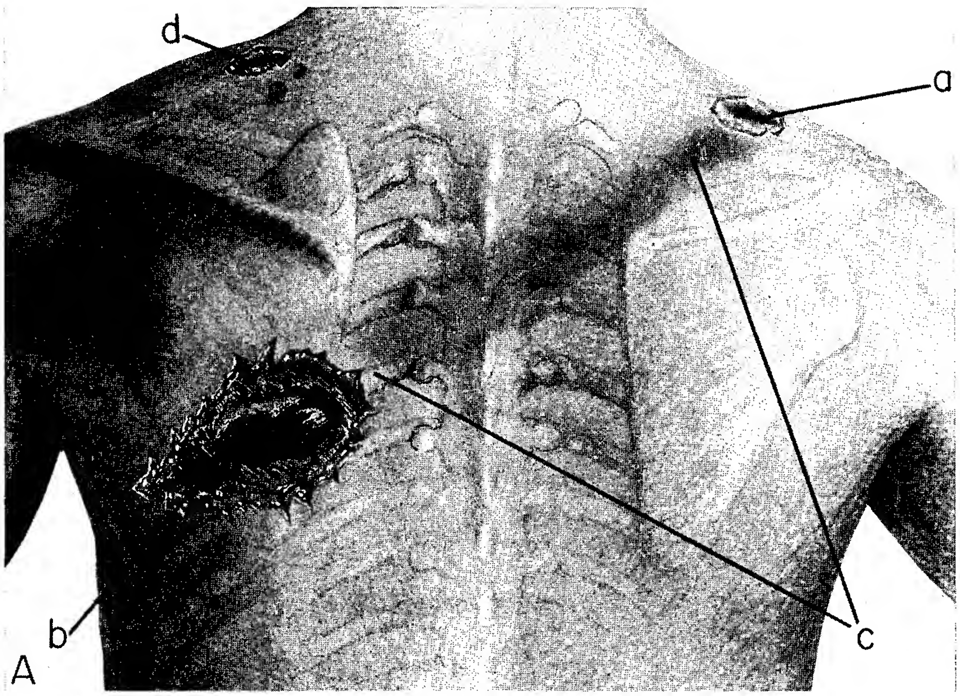

FIGURE 217 (case 12).—Schematic drawings of chest wound with massive chest wall and intrapleural trauma. A. Posterior aspect of chest showing: Wound of entrance in right shoulder (a), large sucking wound with destruction of inferior portion of scapula and fifth rib (b), portion of wound bridged by skin (c), and second wound in left shoulder, with two small foreign bodies (d).

The pleural cavity was opened by resection of the comminuted fifth rib. Intrapleural bleeding was occurring from the fifth intercostal artery (fig. 217B), which was secured at once; 500 cc. of blood was aspirated from the pleural cavity. A huge hematoma occupied the left upper pulmonary lobe. The bone fragments in the lung were removed, and a small laceration was closed, but no pulmonary tissue was resected.

Closed catheter drainage was instituted posterolaterally in the left eighth intercostal space. The wound and the pleural cavity were lavaged with physiologic salt solution. The pleura was closed by suturing the subscapularis and posterior serratus, and then closing the trapezius and latissimus dorsi over this suture line, as a reinforcing layer (fig. 217C). The trapezius on the right was debrided and closed. The whole wound was left open down to the muscle layers.

Bronchoscopy was performed at the conclusion of the operation. A small amount of bloody mucus was aspirated from the trachea, and larger amounts from both main bronchi.

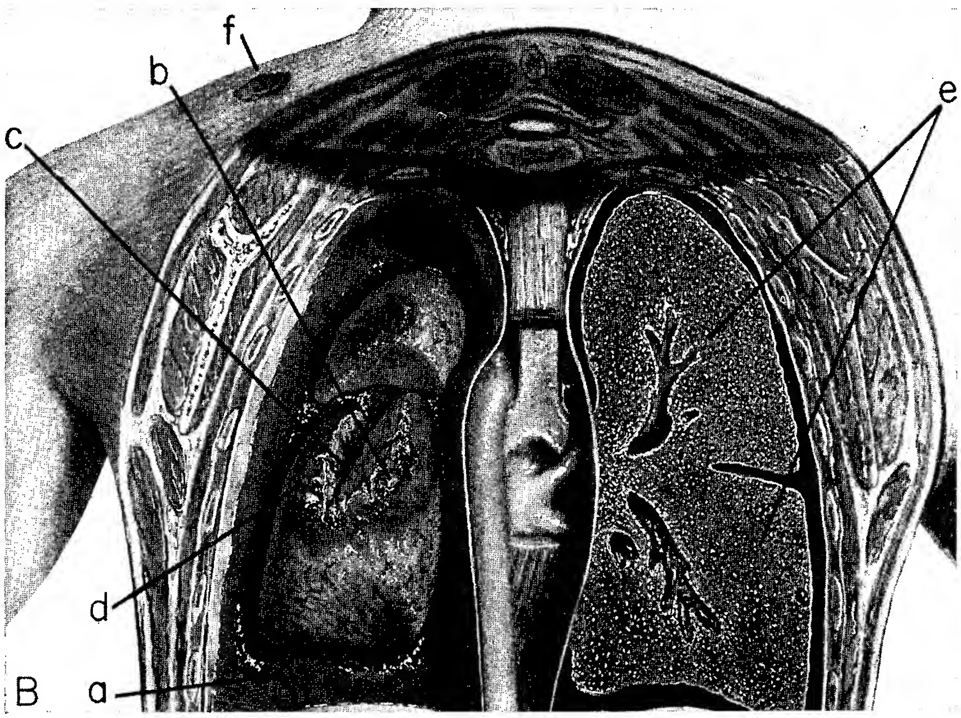

FIGURE 217.—Continued. B. Findings at thoracotomy: Massive hemopneumothorax, with hemorrhage from fifth intercostal vessels (a), rib fragments in left lung (b), laceration of left lower lobe of lung (c), hematoma formation (d), wet lung diagramed on right side (e), and superficial wound of left shoulder (f).

The patient was given 550 cc. of blood during the operation. Immediately after it was concluded, his pulse was irregular, but thereafter the major postoperative problem was keeping the tracheobronchial tree clear.

Roentgenograms before operation (fig. 218A) had showed massive left hemothorax and haziness of the right lung. There was some improvement in expansion of the left lung after thoracentesis (fig. 218B). On the ninth postoperative day, the left lung had almost completely expanded, and both lungs were dry.

After operation, there was considerable drainage (about 500 cc. daily) for the first 2 days; the loss of blood was covered by transfusions.

Delayed primary closure of all wounds was carried out at the 46th General Hospital in the base.

Management in the Zone of Interior.—When the patient was evacuated to the United States on 18 October 1944, the lung had completely expanded, and the hematoma had completely resolved. He was given a disability discharge on 8 May 1945, at Madigan General Hospital, Tacoma, Wash., limitation of motion of the scapula being the main problem.

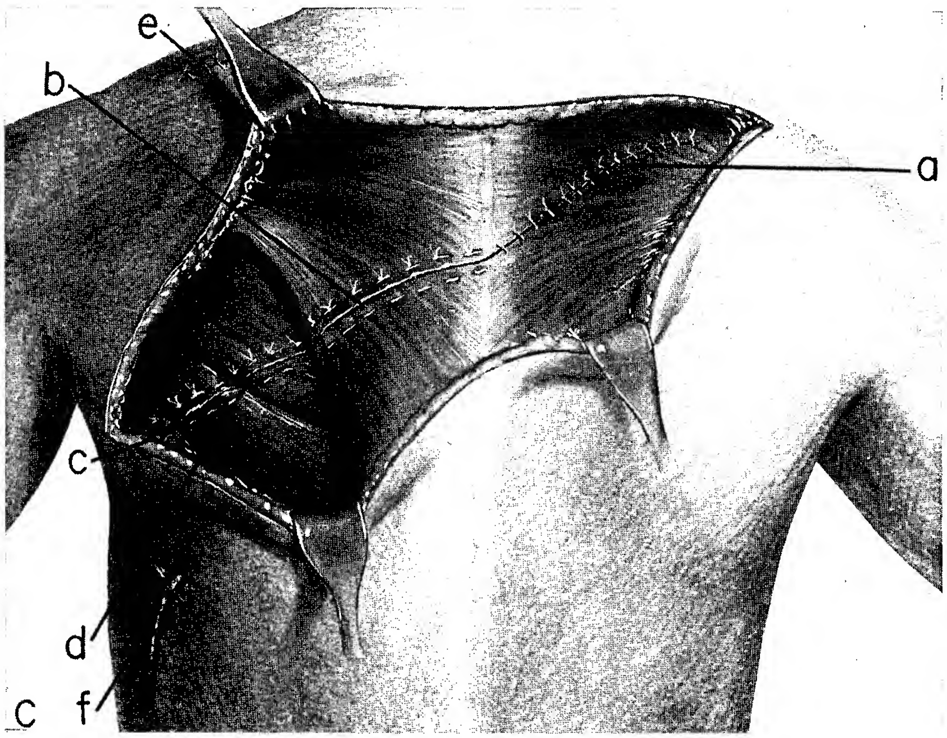

FIGURE 217.—Continued. C. Diagram depicting types of muscle closure: Right trapezius closure demonstrating simple interrupted sutures (a), left trapezius closure demonstrating mattress type sutures (b), left latissimus dorsi (erector spinae group not closed) (c), infraspinatus, skin and superficial fascia left open, wound packed down to muscle layer (d), closure of superficial left shoulder wound (e), and closed intrapleural drainage tube (f).

Followup.—A personal communication from this patient on 6 December 1960 stated that he had been employed as a truck driver for the past 14 years. He complained of soreness and stiffness around the left scapula, of lack of much grip in the left hand for heavy lifting, and of inability to do work involving raising the hand to the level of the shoulder. Although the chief complaint was referable to the shoulder, the patient stated that when he jumped from a truck platform, a distance of 2 or 3 feet, he sometimes spat up blood the following day. He had trouble sleeping on the left side, because of pain in the left shoulder, but he had no difficulty in breathing, and the occasional hemoptysis, the cause of which is not known, was so slight that he had never bothered to seek medical attention for it.

Comment.—This patient had an extensive sucking wound of the chest wall, with continued hemorrhage into the left pleural cavity. The original trauma was complicated by the wet lung syndrome, with bilateral pulmonary edema, and was further complicated by morphine poisoning. Resuscitation

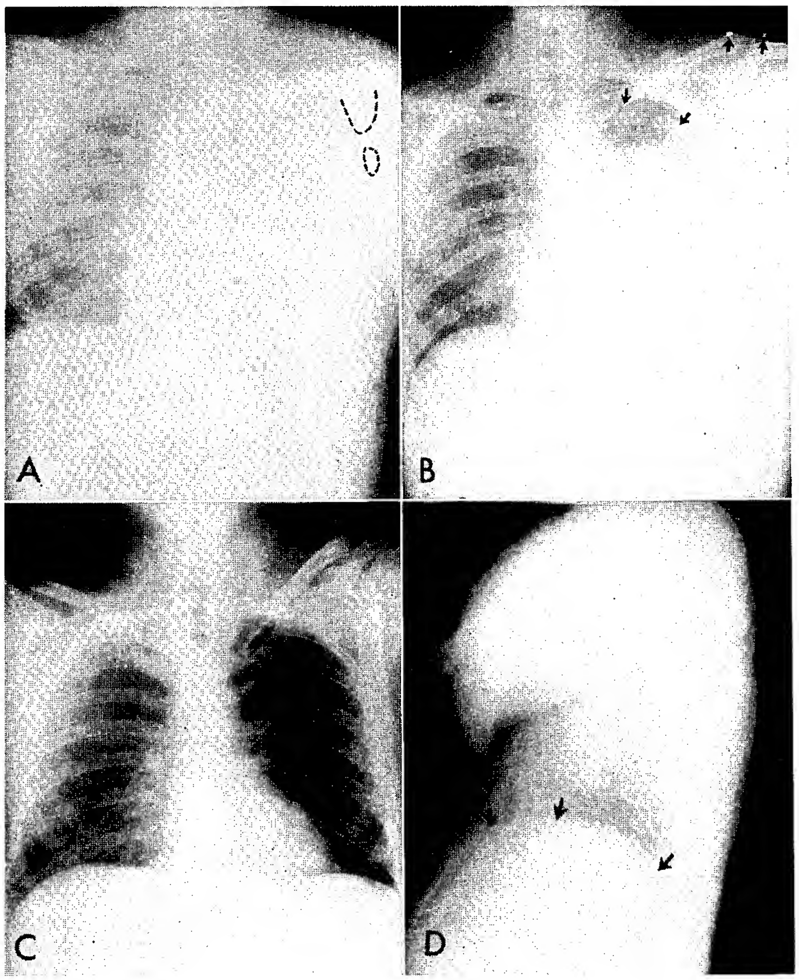

FIGURE 218 (case 12).—Serial roentgenograms in thoracic wound complicated by massive hemothorax. A. Posteroanterior roentgenogram, 21 September 1943, immediately after wounding, showing massive left hemothorax, with slight shift of mediastinum, and haziness of right lung, due to wet lung syndrome. A defect in left scapula is faintly seen. B. Posteroanterior roentgenogram, showing some improvement in expansion of left lung after aspiration of blood in left pleural cavity. Appearance of right lung is not materially altered. Two small foreign bodies are now visible in left shoulder. C. Posteroanterior roentgenogram, 23 November 1960, 17 years after wounding, showing clear lung fields, except for prominent bronchovascular markings. Note bridging of fourth, fifth, and sixth ribs. Heart and mediastinum are normal, and diaphragmatic angle is clear. D. Lateral roentgenogram, 23 November 1960, showing sharp costophrenic angles. These findings are approximately normal and do not explain occasional hemoptyses reported by this patient.

covered 21 hours, but the time occupied in stabilizing him was well spent, for he tolerated corrective surgery well. It is gratifying that for the past 14 years he has been able to work as a truck driver, and that his residual disability is only minor. This is the only patient in the 163 survivors followed up who gave a history of occasional blood-streaked sputum. Roentgenograms (fig. 218 C and D) offer no explanation.

RETAINED FOREIGN BODIES

Retained foreign bodies were observed in 102 of these 167 cases. In 35 instances, they were in the chest wall, in 21 in the pleura, in 36 in the lung, and in 10 in the mediastinum.

These objects always presented a difficult problem in forward hospitals, for the decision as to their removal was frequently delicate. Those in the chest wall were most often removed during debridement at the field hospital. They were usually accessible without a prolonged search, and if they were not in the original wound of entry, they could be removed by a simple counter-incision.

Foreign bodies in the lung and the pleura were not removed as part of traumatic thoracotomy at field hospitals unless they were readily accessible or were believed to lie so close to vital thoracic organs as to constitute a potential danger to them.

Only 13 operations were done for the removal of foreign bodies in base section hospitals, in only 1 instance because of pulmonary hemorrhage. One patient, after an uneventful immediate postoperative course, died 2 months later of hepatitis and jaundice. He had multiple wounds of the head and trunk, and the sucking wound of the chest was complicated by the wet lung syndrome. In this case, a foreign body in the pericardium was removed when the sucking wound was closed. The pulmonary object was not accessible, and its removal would have meant an additional incision and undue prolongation of the operation. It is possible, though highly unlikely, that the retained object was a factor in the fatal outcome.

Only two foreign bodies were removed in this series in Zone of Interior hospitals. One was removed because of a delayed air leak, and the other was removed during closure of a colostomy. Of the 41 patients with retained metallic foreign bodies who were evacuated to the Zone of Interior, only the patient just mentioned, with the delayed air leak, developed symptoms that required its removal.

Case 13

Management overseas.—This 29-year-old artilleryman was wounded in the left shoulder by a high explosive shell fragment at 1146 hours on 29 November 1943 near Ardo, Italy. The wound was dressed with sulfonamide powder at a battalion aid station, where the patient was also given morphine (gr. ½) and sulfadiazine (15 gr.) by mouth.

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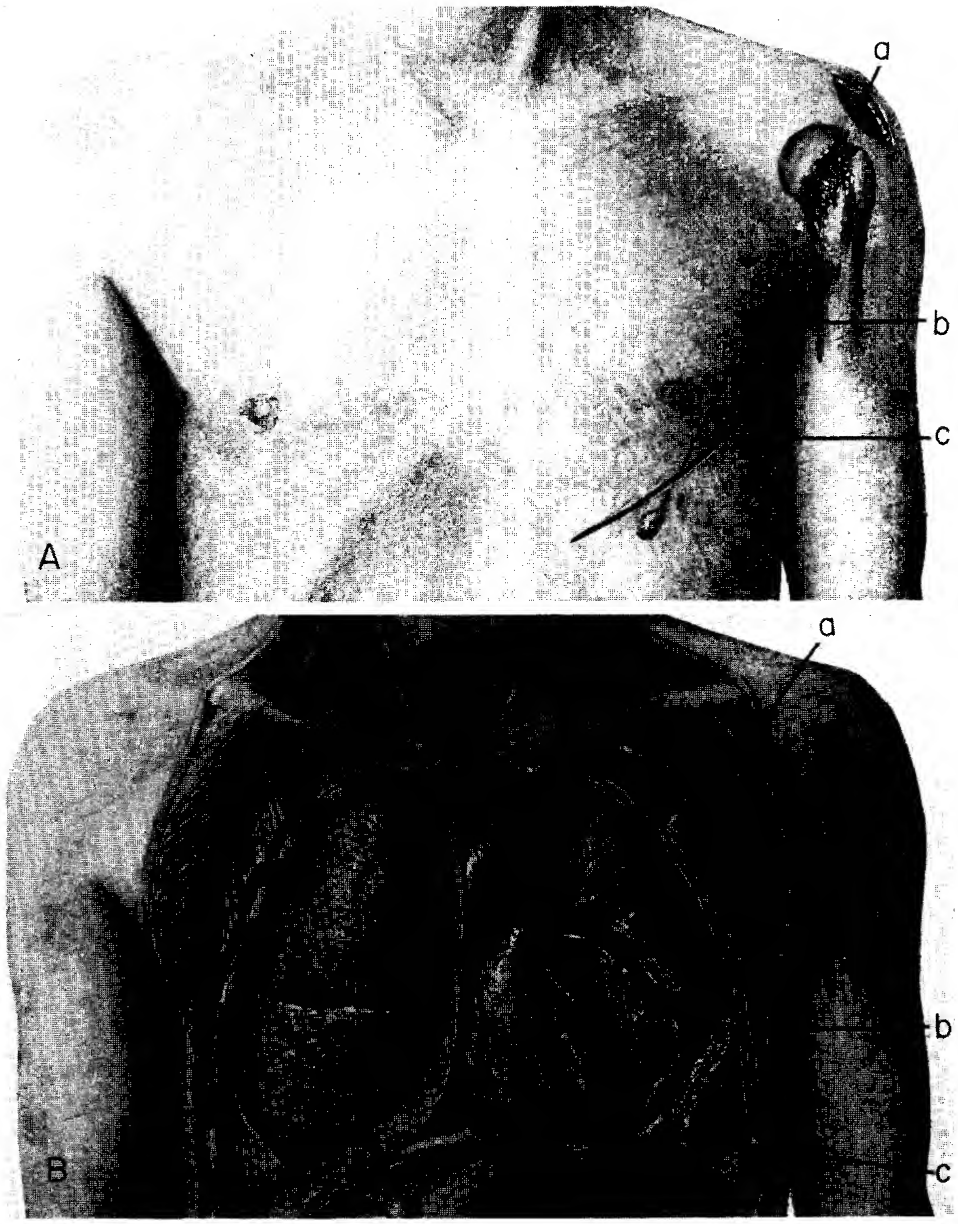

FIGURE 219 (case 13).—Schematic showing of chest wound with retained foreign body. A. Wound: Penetrating shell-fragment wound of left shoulder, with fracture of left humerus (a), passage of missile through chest wall and lung with lodgment in left mid thorax (b), and incision for elective thoracotomy (c). B. Findings at thoracotomy: Large hematoma of left upper lobe (a), hematoma and laceration, left lower chest wall extending down to diaphragm (b), and foreign body in lung adjacent to heart (c).

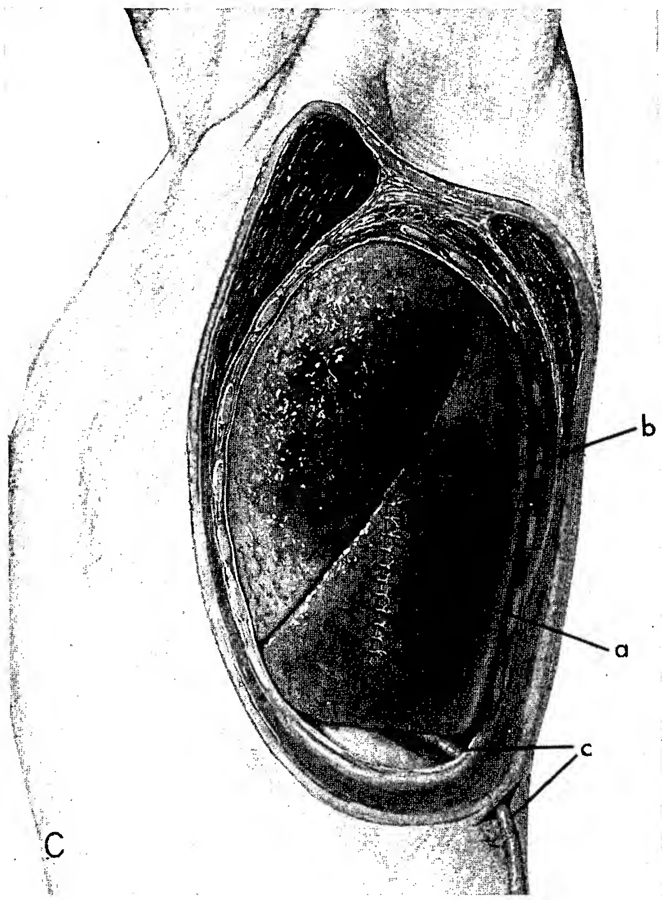

FIGURE 219.—Continued. C. Diagram of left lung at conclusion of operation following removal of shell fragment. Repair of laceration of left lower lobe with two layers of interrupted sutures of fine silk (a), hematoma of upper portion of left upper lobe, which was not disturbed (b), and water-seal intrapleural drainage tube (c).

When he was admitted to the 94th Evacuation Hospital at LePezze at 1410 hours, examination revealed a 2-cm. penetrating wound of the left deltoid region (fig. 219A) but no other thoracic injuries. He complained of considerable chest pain and was dyspneic, orthopneic, and coughing up blood. The blood pressure was 128/60 mm. Hg, the pulse 128, and the respirations 38. Breath sounds were absent over the left chest, and the heart was shifted slightly to the right. The right lung was clear. Roentgenograms (fig. 220A) showed a left hydropneumothorax, with a foreign body in the left cardiac shadow, fractures of the sixth, seventh, and eighth ribs, and haziness of the right lung. There was also a fracture of the left humerus.

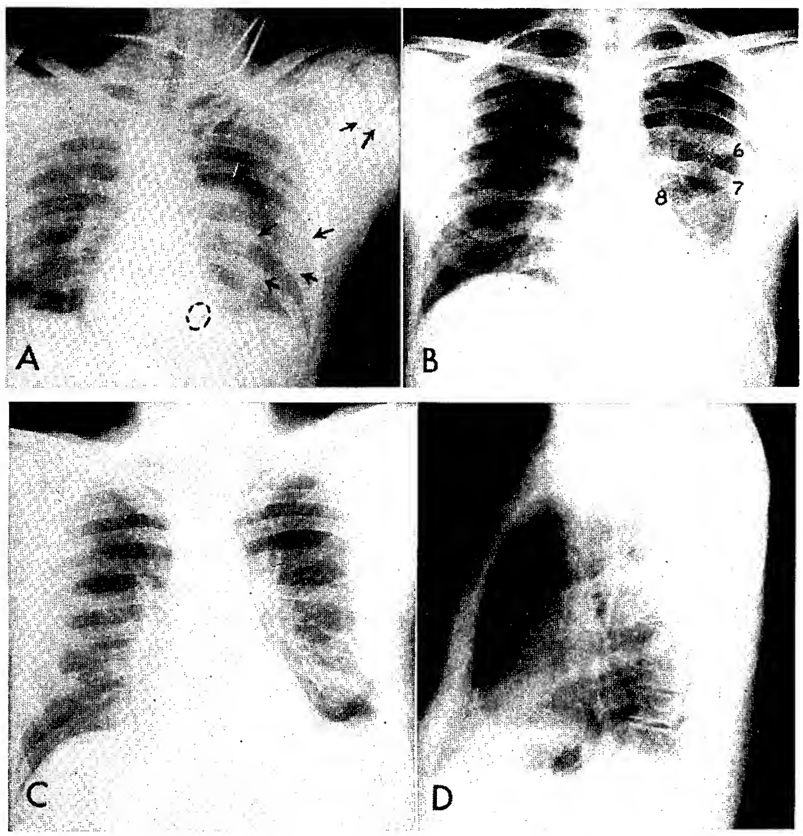

Figure 220 (case 13).—Serial roentgenograms in wound with intrapulmonary foreign body. A. Posterolateral roentgenogram, 29 November 1943, immediately after wounding, showing foreign body in left cardiac shadow; extensive collapse of left lung; fractures of sixth, seventh, and eighth ribs on left; fracture of left humerus; and haziness of right lung. B. Posterolateral roentgenogram, 7 December 1943, showing expanding left lung and resection of segments of sixth, seventh, and eighth ribs. Right lung and cardiac shadows are normal. C. Posteroanterior roentgenogram, 2 December 1960, 17 years after wounding, showing healed fractures of sixth, seventh, and eighth ribs on left; tenting of left diaphragm and blunting of left costophrenic angle. Note prominent bronchovascular markings. D. Lateral roentgenogram on same date, showing left pleural shadow anteriorly and deep posterior costophrenic angle. Note clear lung field.

After thoracentesis, which yielded 800 cc. of air and 800 cc. of blood, a transfusion of 500 cc. was given. A second thoracentesis, performed because of signs indicating a reaccumulation of fluid and air in the left pleural space, yielded 500 cc. of blood.

Thoracotomy was carried out through an elective incision 7 hours after admission, through a left posterolateral incision over the seventh rib, because of the continued reaccumulation of air and blood in the left hemithorax and also because the foreign body was in the region of the cardiac shadow. Fragments of the sixth, seventh, and eighth ribs were resected, and the pleural cavity was opened through the bed of the eighth rib. The sixth intercostal muscles were bleeding and were ligated, and fragments of ribs were removed from the lung. A huge hematoma (fig. 219B) occupied the upper portion of the left lower lobe. The laceration in the lung extended down to the diaphragm, where the foreign body was felt in the pulmonary substance next to the pericardium, which was not involved. The foreign body was removed (fig. 219C) and the lung was repaired with two layers of mattress sutures of fine silk. The hematoma was not disturbed. The chest wall was closed in layers from the pleura to the skin, and closed intrapleural catheter drainage was instituted.

The wound in the deltoid was debrided, and a small sequestrum of the left humerus was excised. The wound was packed open with fine-mesh gauze.

At the conclusion of the operation, bronchoscopy was performed and a large amount of bloody mucus was obtained from both bronchial trees.

The postoperative course was uneventful. Roentgenograms 8 days after wounding (fig. 220B) showed satisfactory expansion of the left lung. The patient was evacuated to the base on the 13th postoperative day. The shoulder wound healed by second intention.

Management in the Zone of Interior.—The only active therapy which the patient required in the Zone of Interior was physiotherapy to the left arm. He received a disability discharge.

Followup.—The patient has worked as a salesman since his discharge from the Army and has no complaints referable to the chest wound.

Roentgenograms (fig. 220C and D) made in December 1960, 17 years after wounding, showed no abnormality except for some obliteration of the costophrenic angle and the thickening of the axillary pleura.

Comment.—In this case, a wound of the shoulder was associated with extensive damage to the chest wall and the left lung. Thoracotomy through an elective incision was performed on the indication of continued bleeding, leakage of air into the left pleural cavity, and the possibility of cardiac damage from a retained foreign body. At operation, the intercostal vessels were found to be the source of the intrapleural hemorrhage. The intrapulmonary foreign body was removed at operation, but the large hematoma was not disturbed, and satisfactory healing of the lung followed.

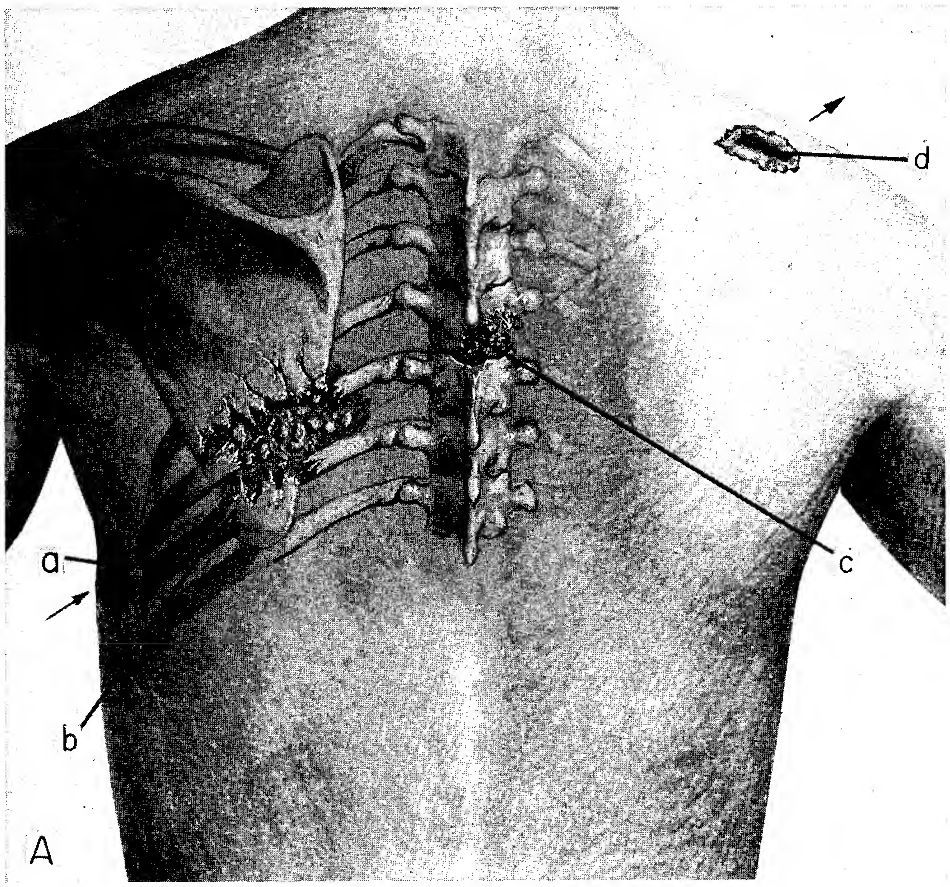

FIGURE 221 (case 14).—Schematic showing of chest wound with retained foreign bodies (rib fragments) in lung. A. Wound: Wound of entrance in left lateral chest wall (a), fracture of left scapula (b), fracture of spine of fourth dorsal vertebra (c), and wound of exit (d).

Case 14

Management overseas.—A 20-year-old infantryman received a bullet wound of the left chest at 0800 hours on 12 January 1943. A sulfonamide-powdered dressing was applied to the wound at a battalion aid station at 0830 hours, and he was given a half grain of morphine and a unit of plasma. Two additional units of plasma were given at a collecting station because of persisting shock.

When he was admitted to the 94th Evacuation Hospital at 1130 hours, he was orthopneic and somewhat comatose and was coughing up blood. He complained of severe pain in the left chest, neck, and abdomen. The blood pressure was 102/70 mm. Hg, the pulse 142, and the respirations 42. There was considerable external bleeding. There was a 3-cm. sucking wound in the left

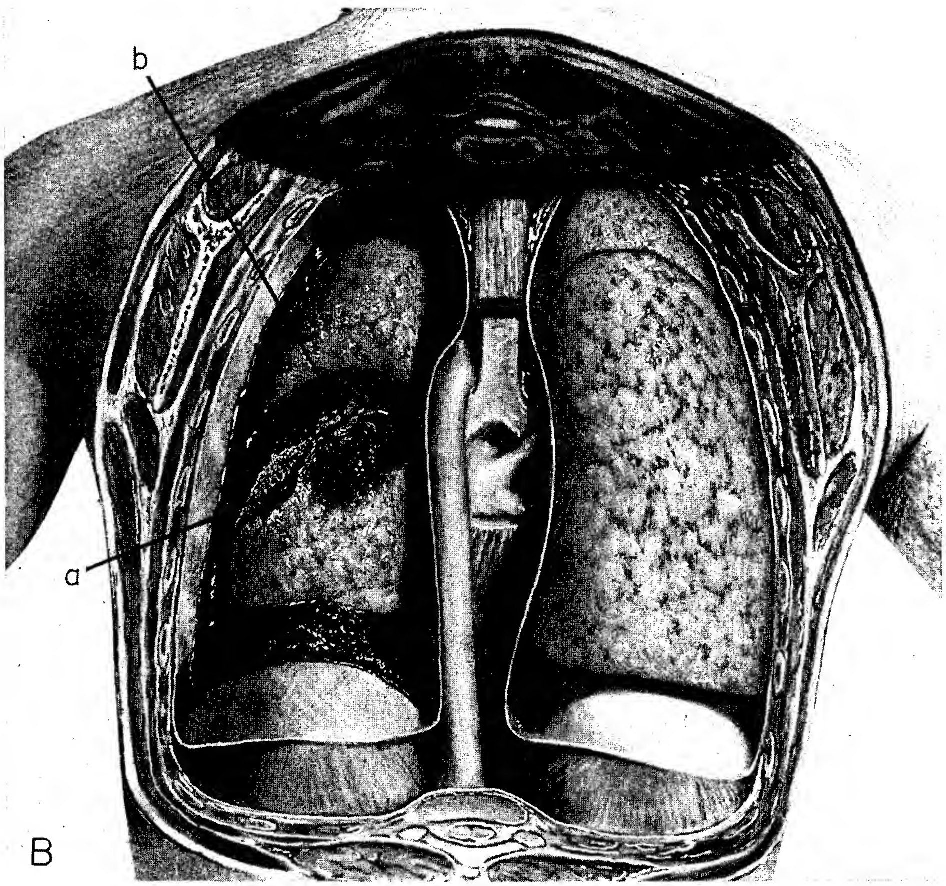

FIGURE 221.—Continued. B. Findings at thoracotomy: Laceration of lung (a) and fragments of fractured rib in hematoma occupying apex of left lower lobe (b).

lateral chest wall (fig. 221A) and a 4- by 5-cm. wound at the base of the neck posteriorly on the right. The sucking wound was immediately packed.

Further examination revealed much crepitus over the posterior chest wall, absent breath sounds on the left, and dullness and signs of fluid in the lower half of the left chest (fig. 222A). The right lung was fairly clear except for occasional rales.

Oxygen was administered and bronchial catheter suction begun. Aspiration of the left chest produced 500 cc. of air and 800 cc. of blood. A slow transfusion of 1,000 cc. of blood was given.

At 2020 hours, about 9 hours after the patient's admission, his blood pressure was stable, the pulse had dropped to 110 and the respirations to 28. He was considered fit for surgery.

The wound of entrance was debrided along the left lateral chest wall, and the incision was extended upward across the chest to the base of the neck on

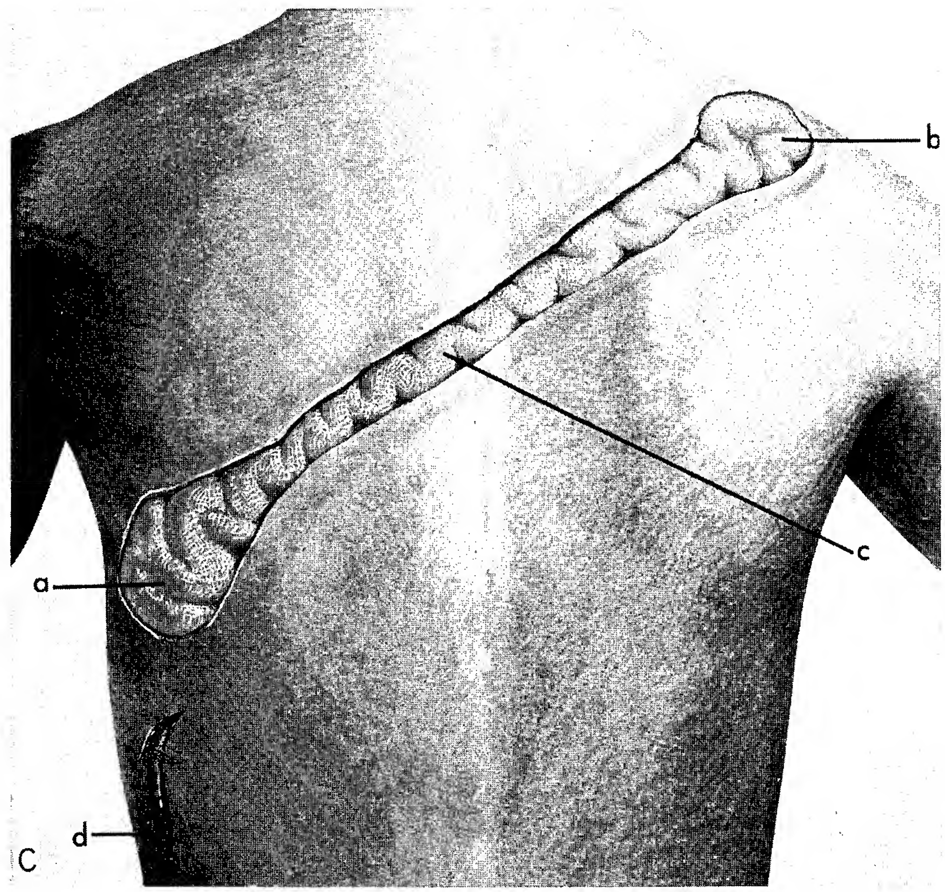

FIGURE 221.—Continued. C. Appearance of wound at conclusion of operation: Wound of entrance (a) and wound of exit (b). Wound has been left open down to deep muscle layer and packed with fine-mesh gauze (c). Closed pleural drainage tube is in situ (d).

the right. The muscles were debrided. The spinous process of the fourth dorsal vertebra, which was fractured, was excised, as was the extensively fractured lower third of the left scapula. Fragments of the fractured fifth rib were also excised. The pleura was then opened through the bed and interspace of the fifth rib, and three bony fragments were removed from the apex of the left lower lobe, which was occupied by a large hematoma (fig. 221B). The lung was slightly debrided, and all air leaks were closed with interrupted sutures of fine catgut. The pleural cavity was lavaged with 1,500 cc. of physiologic saline, after which a catheter was placed in the eighth intercostal space and connected with a closed system. The deep muscle layers were approximated with interrupted sutures of fine cotton. The remainder of the wound was left open and was packed with fine-mesh gauze (fig. 221C).

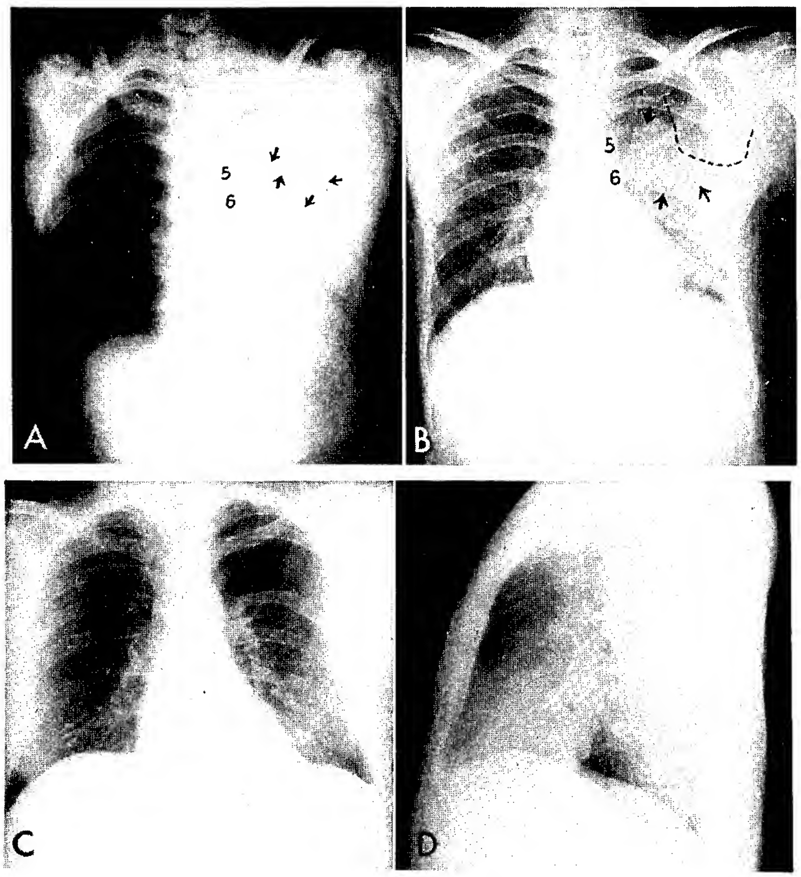

FIGURE 222 (case 14).—Serial roentgenograms of thoracic wound with retained foreign bodies (rib fragments) in lung. A. Posteroanterior roentgenogram of chest, 1 January 1943, immediately after wounding, showing diffuse haziness and fluid in left chest; shift of heart to right; and fractures of fifth and sixth ribs and left scapula. B. Posteroanterior roentgenogram of chest, 12 January 1943, after resection of portion of fifth rib and scapula on left. Note hematoma still evident in lower lobe of expanded left lung. C. Posteroanterior roentgenogram, 18 November 1960, more than 17 years after wounding, showing partial absence of fifth and sixth ribs; slight blunting of left costophrenic angle; and increased bronchovascular markings in lung, which otherwise is clear. D. Lateral roentgenogram on same date, showing sharp costophrenic angles and prominent bronchovascular markings.

At the conclusion of the operation, considerable blood and mucus were aspirated from both major bronchi through the bronchoscope.

The postoperative course was satisfactory. When the intercostal tube was removed on the fourth day, after it had ceased to function, the temperature was 100° F., the pulse 90, and the respirations 22. When the patient was evacuated to the base section on the 12th day, roentgenograms (fig. 222B) showed good expansion of the left lung.

Management in the Zone of Interior.—The patient was evacuated to the Zone of Interior after delayed primary wound closure in a base section hospital. He required no active treatment there, and was given a disability discharge.

Followup.—This patient reported in November 1960 that he was working as a diesel railroad engineer and was in good health. He was married and had two children. Roentgenograms made at this time (fig. 222 C and D), 17 years after wounding, showed essentially negative lung findings.

Comment.—In addition to a sucking wound and extensive damage to the muscles of the posterior chest wall, this patient had extensive fractures of the ribs, scapula, and a spinous process, which resulted in numerous bony foreign bodies. Although this is an area in which anaerobic cellulitis is always a possibility, healing of the lung and the chest wall occurred without pneumonitis, abscess formation, or other infection. Early, careful debridement, with removal of the bony fragments, undoubtedly was the most important factor in the good recovery and subsequent absence of serious disability. The role of sulfanilamide, which was applied locally and given by mouth, is much less certain.

POSTDISCHARGE FOLLOWUP

It has been possible to follow the course in civilian life of 119 of the 163 survivors in this series of combat casualties with chest wounds since their discharge from the Zone of Interior hospitals in which they were kept until their wounds had healed and their lungs had expanded. When they were released, their chest roentgenograms usually showed good healing of the bony cage and clear lung fields except for pleural adhesions and thickening. The followup periods ranged from 3 to 17 years and averaged 5.6 years.

Roentgenologic Observations

Subsequent roentgenograms usually revealed substantially the same findings as the predischarge films, although there had often been further clearing of the pleural shadows. The most frequent abnormal findings in the current roentgenograms consisted of pleural adhesions or tenting of the diaphragm, which occurred in 57 cases. These roentgenologic findings are exactly what one would expect to find in civilian patients after thoracotomy for pulmonary, mediastinal, or cardiac surgery.

Other roentgenologic observations included thickening of the pleura in 20 cases, slightly increased or prominent bronchovascular markings in 8 cases, and pulmonary emphysema in 5 cases. The generally inconsequential abnormalities in the roentgenograms described in the 14 case histories just recorded, all of which were taken 16 or 17 years after wounding, are typical of almost all the cases in this series.

Retained Foreign Bodies

Of the 119 patients followed up in civilian life, 41 harbored retained foreign bodies, 35 times in the lung, 4 times in the chest wall, and once each in the liver and in the region of the right diaphragm. All these objects were less than 1 cm. in diameter, and in no instance was a pleural or pulmonary reaction noted about them on roentgenograms.

All of these patients had been observed in all echelons of U.S. Army hospitals, from the combat zone to the Zone of Interior, and in every case it had been predicted that the retained missiles would cause no further difficulties. The prophecy proved correct in all but 1 of the 41 patients. The exception was a 32-year-old infantryman, who had sustained multiple wounds of the arms, legs, and chest at Anzio on 29 May 1944. He was treated at the 11th Field Hospital, where the wounds of the extremities were debrided. The two penetrating wounds of the left chest were also debrided, and a foreign body was removed from the chest wall. On 14 July 1944, a drainage operation was performed for hemothoracic empyema at the 23d General Hospital at Naples, and on 9 February 1945, a chest abscess was drained at Walter Reed General Hospital.

The patient remained well until 3 October 1951, when hemoptysis and a recurrent infection of the lung and the pleura required wedge resection of the left lower pulmonary lobe, which was the site of the retained foreign body. Both operations in the Zone of Interior were performed by Dr. Brian Blades.

This was the only case in this series in which a retained intrathoracic foreign body gave rise to delayed difficulties. The patient represents about 0.6 percent of the 163 casualties who survived to be evacuated from hospitals in the communications zone. From the purely clinical standpoint, therefore, there seems to be no reason for early removal of small (less than 1-cm.) asymptomatic missiles. All such objects, of course, should be removed whenever this can be conveniently done in the course of surgery on other indications.

Symptoms Referable to the Chest

Most of the patients followed up in civilian life had no symptoms referable to the chest. The few who had symptoms complained chiefly of pain and dyspnea. The evaluation of any posttraumatic pain is notoriously difficult, particularly when industrial compensation is part of the picture. Since dis-

ability and pensions were involved in all of these chest injuries, the problem was much the same as in civilian compensation cases.

Hemoptysis was recorded only twice. In one case, just described, the bleeding could be attributed to a retained foreign body. In the other, there was occasional slight streaking of blood when a driver jumped off his truck (case 12, p. 508). The origin of the bleeding in this case is not apparent; the roentgenogram, taken 16 years after wounding, shows no significant findings.

Severe chronic cough, chronic bronchopulmonary infection, bronchiectasis, and chronic lung abscess, the heritage of so many thoracic casualties of World War I, did not appear in any of these 119 patients.

Psychoneuroses

There is thus a gratifying paucity of physical complaints in these 119 patients followed up in civilian life. In another area, however, unhappy dividends of battle wounds are apparent. In 18 cases, reports in Veterans' Administration files indicated some form of psychoneurosis. These were probably the most serious posttraumatic sequelae observed. In two instances, the patients had sustained blast injuries and had had severe cerebral symptoms immediately afterward, but all of these symptoms had cleared up before their discharge from Zone of Interior hospitals.

It seems highly likely that the psychoneuroses in these 18 cases are far more closely related to the total experience of war and of wounding than to the chest wound in itself. They are also both a factor in, and an index of, the casualty's postwar adjustment to civilian life.

Development of Thoracic Disease

Whether the postdischarge development of thoracic disease is related to thoracic trauma is a matter still to be settled. This is the present situation in these 117 men:

1. A number were hospitalized at various times for pneumonia and other acute respiratory infections, but the number was probably no greater proportionately than would be expected in the general population.
2. Two patients developed pulmonary tuberculosis, one after reenlistment during the Korean War. Both cleared well.
3. One patient, in 1952, developed a bronchogenic carcinoma on the same side as the penetrating wound of the chest. He died a year after pneumonectomy.

The incidence of posttraumatic thoracic disease was thus very small in these 119 patients. Whether the figures can be taken at their face value is another matter. The number of patients followed up is small, and the series is not representative in one sense, that it includes only a few patients who were not cared for in the Veterans' Administration hospitals and clinics. Further-

more, carcinoma of the lung will undoubtedly be seen in other patients, even in this small group, as they pass into the age range in which this and other forms of malignancy are more common.

SUMMARY AND CONCLUSIONS

The patients in the series reported in this chapter, like all patients with chest wounds encountered after March 1944, were treated by policies of management developed, for the first time in medicomilitary history, in the Mediterranean theater. In general, these policies were conservative, and it is fair to say that no patient in the series who was treated without thoracotomy at initial wound surgery because he was not considered to need that operation suffered in any way because his chest was not widely opened.

In summary, these policies and practices were as follows:

1. Careful stabilization of the cardiorespiratory physiology was the first principle of management and was vital to the success of every procedure from simple debridement of the chest wall to extensive intrathoracic surgery. That is, no matter what the wound, the first attention was directed to its effect on the lung and the heart. The single possible exception to this generalization was thoracoabdominal wounds associated with shock caused by peritoneal contamination.

2. Debridement of the wound was the first procedure in thoracic wounds. In those limited to the chest wall, nothing else was required.

3. The indications for primary thoracotomy in forward echelons were strictly limited. They included traumatic thoracotomy (sucking wound), thoracoabdominal wounds, continued intrathoracic hemorrhage, leakage of air from the respiratory tract, and injury to vital mediastinal structures (esophagus, trachea, heart, great vessels, and thoracic duct). In retrospect, there seems to be no valid reason to widen these indications. Their standardization, in fact, represented a major contribution to thoracic surgery in World War II.

4. Immediate recognition and intensive treatment of the wet lung syndrome not only reduced the intial surgical mortality but prevented the late sequelae of pulmonary atelectasis and bronchopulmonary suppuration. These were frequent sequelae of chest wounds in World War I. There were no complications of this sort in this series.

5. In severe wet lung, in which pain in the chest wall was an important factor, treatment consisted of intercostal nerve block, tracheobronchial aspiration, and the administration of oxygen under intermittent positive pressure. All of these techniques have been carried over to civilian thoracic surgery since the war. In fact, intermittent positive pressure oxygen therapy, which was used in the Mediterranean theater for the first time in medical history, in the management of severely wounded thoracic casualties before and after opera-

tion, is now almost standard in the management of many pulmonary and cardiac conditions for which thoracic surgery is done.

6. Prompt aspiration of hemothoraces increased the vital capacity of the lung and permitted the evaluation of the degree of intrapleural hemorrhage. In some instances, this measure undoubtedly prevented the deposition of fibrin and the development of the so-called captive lung. In no instance was there any evidence that bleeding into the chest was increased by this technique, as many surgeons, before the war, had predicted.

7. Hematomas, even if they involved an entire pulmonary lobe, responded well to conservative treatment and furnished no indications for resection of the involved tissue. These hematomas resolved with almost no pathologic pulmonary residua.

8. Pulmonary lacerations usually responded to intercostal decompression by the closed technique. If they did not, thoracotomy, with simple suture, was the indicated treatment. Neither lobectomy nor resection was required. In fact, these followup studies, as well as other studies, show that such operations had no place in the initial surgery of war casualties. Even localized (segmental or less) resections were almost never indicated; only one was performed in this series. The explanation is the tremendous recuperative powers of the lung together with its dual blood supply and elaborate lymph drainage.

9. Sucking wounds of the chest required immediate occlusion of the chest wall defect. After resuscitation of the patient from the cardiorespiratory point of view, traumatic thoracotomy could be performed with a low mortality and generally excellent results.

10. Patients with blast injuries who survived their stay in forward hospital could be returned to civilian life with few cardiorespiratory symptoms and only moderate residua caused by damage to the cerebrum or tympanum.

11. Retained foreign bodies, if they were not producing hemorrhage, persistent air leaks, or esophageal trauma, were best handled at the base section, where the patient was in better condition to tolerate the necessary procedures. Asymptomatic foreign bodies in the lung, pleura, and mediastinum which were less than 1 cm. in diameter were usually well tolerated, if the evidence of this series is to be believed.

12. Patients with thoracoabdominal wounds handled by the principles employed for thoracic and abdominal surgery in the Mediterranean theater were returned to civilian life with few or no cardiorespiratory or gastrointestinal symptoms.

13. Patients with mediastinal injuries seldom survived to reach forward hospitals. When they did, gratifying long-term results were achieved if they were managed by the principles and practices just described.

The postwar followup of the patients in this series furnishes every cause for encouragement as to the general results of these principles and practices. The series is small, it is true, but it is entirely unselective except in the sense that the patients were included in it because the original information concern-

ing their wounds was available and their subsequent records were complete enough to be useful.

Only 4 of the 167 severely wounded casualties in this series who survived initial wound surgery in forward hospitals died in base hospitals, and no deaths attributable to thoracic wounds occurred in casualties followed up in Zone of Interior hospitals or in those traced in civilian life.

From the records, and from personal correspondence with a number of men in the group, it was evident that practically all of them were gainfully employed, usually full time; that they were married and had families; that they were leading useful civilian lives; and that, with few exceptions, they considered themselves well from the standpoint of their chest wounds.

The assumption also seems warranted, as already intimated, that the majority of patients in the original panel of casualties (822) do not appear in this followup because they regarded themselves well. Those who reported to the Veterans' Administration are a group with more persistent ill effects from their wounds—frequently not their thoracic wounds—or a group of psychoneurotic patients whose attention was focused on their old chest injuries.

One emerges, therefore, from an analysis of these records with the impression that if the patients in the series may be assumed to be representative, the great majority of casualties who survived chest wounds were really rehabilitated and restored to normal, useful lives. If this impression is correct (and there are no data to the contrary), it furnishes strong evidence of the validity of the principles and practices of thoracic surgery developed in the Mediterranean theater in World War II and recorded in detail in these volumes.

APPENDIX

Special Reports and Statistical Data

B. Noland Carter, M.D., and Michael E. DeBakey, M.D.

Throughout this volume, statistical and other material has been cited from the clinical experiences in World War II of various organizations and individuals. This appendix summarizes the clinical-statistical data on thoracic surgery of the activities of:

1. The 2d Auxiliary Surgical Group in the Mediterranean (formerly North African) Theater of Operations, U.S. Army, from the final report made by Maj. (later Lt. Col.) Reeve H. Betts, MC; Maj. (later Lt. Col.) Paul C. Samson, MC; Maj. Lyman A. Brewer III, MC; Maj. (later Lt. Col.) Lawrence M. Shefts, MC; and Maj. Thomas H. Burford, MC.
2. The 5th Auxiliary Surgical Group in the European Theater of Operations, U.S. Army, from the final reports on 1,068 war wounds of the thorax and abdomen, made by Maj. William H. Falor, MC; Maj. Charles B. Burbank, MC; and Maj. (later Lt. Col.) Elmer D. Gay, MC.
3. The Kennedy General Hospital thoracic surgery center, Memphis, Tenn. The material used is an analysis of the first 500 thoracic casualties received in the center after it became fully operational. The report was prepared by Maj. Earle B. Kay, MC, and Lt. Col. Richard H. Meade, MC.

The original detailed reports are on file in The Historical Unit, U.S. Army Medical Service.

2D AUXILIARY SURGICAL GROUP

Basic Data

Between the Tunisian landings in November 1942 and the end of the war in Italy in May 1945, the 27 general surgical and 5 thoracic surgical teams of the 2d Auxiliary Surgical Group[1] cared for approximately 22,000 battle casualties in North Africa, Sicily, Italy, southern France, and Germany. The 3,154 abdominal injuries included in this material are analyzed in another volume of this series.[2]

During the specified period, surgeons of the 2d Auxiliary Surgical Group cared for 1,364 casualties with thoracic wounds, 135 of whom (9.89 percent) died, and 903 casualties with thoracoabdominal wounds, 247 of whom (27.35 percent) died. This is a total of 2,267 casualties with thoracic and thoracoabdominal wounds and 382 deaths (16.85 percent).

Among the casualties with only chest wounds were 115 civilians and prisoners of war, of whom 19 (16.52 percent) died. This leaves 116 deaths in 1,249 U.S. Army personnel with thoracic wounds (9.29 percent). The following discussion includes only these 1,249 casualties unless otherwise specified.

The figures include all penetrating and perforating wounds encountered by the group surgeons during this period. They do not include injuries limited to the thoracic cage,

[1] The extensive experience of the teams of the 2d Auxiliary Surgical Group with thoracoabdominal injuries is summarized under that heading (p. 136).

[2] Medical Department, United States Army, Surgery in World War II. General Surgery. Volume II. Washington: U.S. Government Printing Office, 1955, pp. 79–333.

without pleural penetration, even though pleural damage sometimes occurred under these circumstances.

In the early days of the Tunisian campaign, a small number of these casualties were operated on in clearing stations. A few were also operated on in beach installations, during the first few days of amphibious landings. With these exceptions, all the casualties received their initial wound surgery in field and evacuation hospitals.

All the deaths occurred in these forward hospitals, for which the figures can be assumed to be complete. On the other hand, casualties were held in forward hospitals only for limited periods, seldom more than 14 days. It must therefore be assumed that a certain number of deaths occurred later, in fixed hospitals and thoracic surgery centers in the base. There is no information on this point, for the attempts at followup that were occasionally made were not successful.

Deficiencies of records.—Many errors and imponderables enter into any records prepared by medical officers under field conditions. There are errors and omissions in these. Yet they are surprisingly complete when one considers the circumstances in which the material was compiled. It was necessary for each team to prepare from four to seven official records on each patient, all in longhand, all without secretarial or stenographic help, and all containing much duplicated material. All post mortem examinations were made by members of the teams, and all protocols were written by them in longhand. During rush periods, when surgeons were working long hours under extremely adverse conditions, their zeal in the preparation of additional records for some future study was naturally limited. The most amazing thing about the records is that they were kept at all.

These statistics and conclusions are based on the overall experience of the surgeons of the 2d Auxiliary Surgical Group. They represent not only individual experiences but the aggregate experiences of all the surgeons. The number of injuries is large enough to warrant conclusions. The casualties were treated over a sufficiently long time, in sufficiently varied climates and terrains, under sufficiently varied conditions, to compensate for some of the variables and to cancel out some of the inevitable errors. The chief justification for the presentation of this clinical-statistical material in detail is that, so far as is known, this is the most extensive study of combat-incurred thoracic and thoracoabdominal wounds that has ever been made.

Chronologic division of cases.—There are a number of reasons for analyzing certain of these data according to whether the casualties were treated before or after 1 May 1944. The date, which is arbitrarily selected, represents a turning point in clinical policies, to which the improved results (a drop in the case fatality rate from 11.27 percent to 8.3 percent) bear witness. Among the factors responsible for this improvement were:

1. Better triage, based on a clarified definition of transportability (vol. I).
2. More rapid evacuation of casualties from the battlefield to the division clearing station.
3. A more correct appreciation of the physiologic components of resuscitation, including the importance of wet lung (p. 207).
4. A clarification of the indications for thoracotomy in forward hospitals and of the limitations of this operation.
5. Improvements in postoperative care.
6. The provision of liberal amounts of blood by a theater blood bank, so that every casualty could be given all he needed.
7. Improvements in anesthesia, as a result of both more adequate equipment and the increased experience of anesthesiologists.
8. The universal availability of penicillin, which after 1 May 1944 could be used in adequate amounts whenever it was indicated.
9. The increased experience of both thoracic surgeons and general surgeons who were called upon to care for thoracic casualties, which is discussed elsewhere as the so-called learning curve (p. 139).

It was the opinion of many surgeons of the 2d Auxiliary Surgical Group that casualties cared for after 1 May 1944 were, generally speaking, more severely wounded than those treated before that date. This is not a matter which lends itself to statistical proof. If the opinion were correct, and if other factors had remained equal, a higher case fatality rate might have been anticipated after that date. Instead, as just pointed out, the rate fell, probably for the reasons just specified.

Wounding Agents and Location of Injuries

In the 1,203 injuries in which this information is available, the wounding agent was a shell fragment in 830 cases, a gunshot wound in 371 cases, and a stab wound in 2 cases.

In 1,240 stated injuries, the right side was involved 602 times (48.55 percent) and the left side 603 times (48.63 percent) ; both sides were involved 35 times (2.82 percent).

In 1,238 injuries, 719 of the wounds were penetrating (58.08 percent), 478 perforating (38.61 percent), and 41 lacerating (3.31 percent).

Shock and Resuscitation

Shock.—Of the 400 thoracic casualties treated before 1 May 1944 (hereafter referred to as Group I) for whom this information was recorded, 149 were not in shock, 67 were in mild shock, 83 were in moderate shock, and 44 were in severe shock. The corresponding data for the 849 casualties treated after 1 May 1944 (hereafter referred to as Group II) indicate that 314 were not in shock, 162 were in mild shock, 190 were in moderate shock and 110 were in severe shock.

Blood and plasma.—During the early fighting in North Africa, plasma was used liberally and blood infrequently. Blood was used in increasing amounts and on broadening indications in the fighting in Sicily and in the first months of fighting in Italy, but the supply was limited, and it was often difficult to obtain until a theater blood bank was established in Naples in February 1944. That circumstance is part of the explanation for the more limited use of blood and the more liberal use of plasma in Group I injuries in this series. On the other hand, there must also be taken into consideration that in the early months of the war, it was believed that plasma was an acceptable substitute for whole blood and that in some quarters, at least, this belief died slowly. The amount of blood and plasma administered to these two groups of casualties therefore depended not only upon their special necessities but upon the availability of whole blood and the original impression of the value of plasma.

It is not thought that the statistics that follow are complete, though they are based on all the specific information recorded on the emergency medical tag and on the records of the hospital in which initial wound surgery was performed. Entries on some additional charts suggested that replacement therapy might have been employed, but the data were not specific and were discarded.

The composite recorded figures for replacement therapy are as follows:

In Group I, 196 or 400 patients (49.00 percent) received plasma in the total amount of 138,200 cc., the average amount per patient being 705 cc. The largest amount given was 2,500 cc.

In Group II, 569 of the 849 casualties (67.02 percent) received a total amount of 351,200 cc. of plasma, the average amount per patient being 617 cc. The largest amount given was 2,750 cc. The drop in Group II of almost 100 cc. in the average per case probably reflected the increased availability of blood at this time and the restriction of plasma to its proper uses.

In Group I, 172 of the 400 patients (43.00 percent) received a total of 179,900 cc. of blood, the average per patient being 1,046 cc. The largest amount given was 3,600 cc.

In Group II, 633 of the 849 casualties (74.56 percent) received a total amount of 753,850 cc., the average amount per patient being 1,189 cc. The largest amount given to a single patient was 7,500 cc.

Autotransfusion was used in 29 patients in Group I, in the total amount of 23,400. The average per patient was 807 cc., and the largest amount thus given was 2,700 cc.

In Group II, 42 patients were treated by autotransfusion, in the total amount of 28,950 cc. The average per patient was 689 cc., and the largest amount given was 2,000 cc. The figures for Group II probably reflect the increased availability of blood; autotransfusion is not a desirable technique if blood can be secured elsewhere.

Other resuscitative measures.—In Group I, 8 of the 400 patients were treated by intercostal nerve block, 53 by thoracentesis (in 1 case via intercostal catheter), and 4 by tracheal aspiration per catheter. Preoperative bronchoscopy to clear the airway was not used in any instance in Group I.

In Group II, 69 of the 849 casualties were treated by intercostal nerve block, 218 by thoracentesis (in 9 cases by intercostal catheter), 25 by tracheal aspiration per catheter, and 8 by bronchoscopy. One must be impressed by the more active measures used in Group II to facilitate deep breathing and coughing and to keep the airway clear. In spite of the time consumed by these additional measures, the average timelag fell from 15.7 hours in Group I to 14.0 hours in Group II.

Measures to control pressure pneumothorax were seldom necessary. This complication was encountered only once in Group I and only 10 times in Group II.

Surgical Procedures

In Group I, 234 of the 400 patients (58.50 percent) were treated only by debridement. In Group II, 534 of the 849 patients (62.90 percent) were thus treated.

In Group I, 67 thoracotomies were performed by general surgical teams in the 243 cases which they handled (27.57 percent). There were 11 deaths (16.42 percent). In this same group, over the same period, 72 thoracotomies were performed in 157 cases (45.86 percent) by thoracic surgical teams, with 10 deaths (13.89 percent).

In Group II, 224 thoracotomies were performed in 623 cases by general surgical teams (35.95 percent), with 27 deaths (12.05 percent). In this same group, 72 thoracotomies were performed in 226 cases by thoracic surgical teams (31.86 percent), with 6 deaths (8.33 percent). The casualties in this group were all cared for after strict limitations had been put upon the use of thoracotomy. This fact is reflected in the much smaller proportion of cases in which the operation was used, as well as in the reduced case fatality rates.

Thoracotomy was performed through the wound in 368 cases, in 156 of which it was necessary to enlarge the traumatic thoracotomy, and by a separate elective incision in 67 cases.

The indications for the operation, according to the 144 charts on which this information was available, were as follows:

Combined thoracic and abdominal wounds (as contrasted to thoracoabdominal wounds) in 63 cases, with 13 deaths.

Bleeding in 36 cases, with 6 deaths.

Injuries to the mediastinum, heart or both in 20 cases, with 2 deaths.

Retained foreign bodies in 11 cases.

Retained bone fragments in 3 cases, with 1 death.

Pulmonary lacerations in 2 cases, with 1 death.

Bronchial injuries in 3 cases, with 1 death.

Injuries of the esophagus in 3 cases, with 3 deaths.

Possible injury of a hilar vessel, pressure pneumothorax, and failure of the lung to expand in 1 case each. The casualty with the vascular injury did not survive.

Analysis of Fatalities

The breakdown of the 116 deaths in 1,249 wounds of the chest in U.S. Army personnel (9.29 percent) was as follows:

53 deaths in 768 debridements (6.90 percent).

- 19 deaths in 234 debridements in Group I (8.12 percent).
- 34 deaths in 534 debridements in Group II (6.37 percent).

54 deaths in 435 thoracotomies (12.41 percent).

- 21 deaths in 139 thoracotomies in Group I (15.11 percent).
- 33 deaths in 296 thoracotomies in Group II (11.15 percent).

9 deaths before, or in the course of, operation.

There were 19 deaths in the 115 wounds in civilians and prisoners of war not included in this analysis (16.52 percent).

Among the 1,249 casualties with chest injuries were 200 who also had associated wounds of major importance, including 63 wounds of the abdomen, 42 severe compound fractures, 39 spinal cord injuries, 15 severe soft tissue wounds, 7 traumatic amputations, and 4 contralateral thoracoabdominal wounds.

There were 46 deaths in these 200 cases (23.0 percent), as compared to 70 deaths in the 1,049 U.S. Army casualties (6.67 percent) whose wounds were limited to the chest or who had associated wounds not of major importance. In all combat injuries, the risk was always greater when the wounds were multiple, and it increased in proportion to the severity of the principal and associated injuries. In many of the cases just listed, the chest wound was obviously of lesser importance than the associated injury.

Causes of Death

In 16 of the 116 deaths in U.S. Army personnel, the cause was not recorded and it was impossible to gather from the scanty notes to what they should be attributed. The 41 separate causes listed for the remaining 100 deaths can be conveniently grouped as follows:

Pulmonary and respiratory causes.—Of the 100 deaths, 28 were due to pulmonary or respiratory conditions. This was the largest single group of deaths, and, from the clinical standpoint, the group most amenable to treatment. In the opinion of the surgeons who cared for these casualties, some of these deaths, at least, must be regarded as preventable.

Seven deaths from pulmonary edema occurred between the first and fourth postoperative days. In every instance, the pulmonary damage was severe. It is not known whether positive pressure oxygen therapy was employed in any of these patients, but in several cases, it was thought that injudicious replacement therapy played a part in the fatality.

In 15 cases, the cause of death was listed as pneumonia. In some instances, exposure on the battlefield, preexisting upper respiratory infection, and the virulence of the organism in relation to the resistance of the host explained both the complication and the fatal outcome.

Four patients died of atelectasis. One died of tracheal obstruction caused by an excessive production of mucus, and another died of wet lung, on the fifth postoperative day. Attempts to improve drainage of the tracheobronchial tree were always vigorous, once the importance of the wet lung of trauma had been realized (p. 207), but occasionally they were not successful. Sometimes there was a recurrence of the tracheobronchial obstruction after it had been relieved, and the stage was then set for the development of atelectasis and pneumonia if prompt, zealous efforts were not made to overcome it.

Shock.—Ten patients died of shock, eight on the day of operation, one on the following day, and one on the second postoperative day.

Nine patients died of renal failure, which in most instances seemed related to their previous state of shock. All these deaths occurred in Group II; earlier in the war, lower nephron nephrosis was not recognized and, as a matter of fact, much about it remained to be clarified when the war ended.

Hemorrhage.—Nine patients died of hemorrhage, as follows:

3 from lacerations of the aorta.

2 from massive intrapleural hemorrhage.

2 from massive intrapulmonary hemorrhage.

1 from mediastinal hemorrhage.

1 from laceration of the vena cava.

The small number of deaths from intrapleural and intrapulmonary hemorrhage (only five when the lacerations of the great vessels are excluded) is striking in view of the emphasis put upon intrathoracic bleeding as a possible cause of death in the prewar discussion of chest injuries.

Cardiac deaths.—There were five deaths from cardiac injuries, three of which had been overlooked, and another death from cardiac tamponade. One of these injuries was complicated by atelectasis. Two other deaths were caused by cardiac fibrillation.

Miscellaneous causes of death.—Other causes of death, which cannot be conveniently grouped, were as follows:

6 deaths from blast injuries, which affected the pulmonary tissues in 4 cases, the mediastinal tissues in 1 case, and the cerebral tissues in 1 case.

4 deaths from clostridial myositis, in 1 instance complicated by pneumonia.

4 deaths from pulmonary embolism.

3 deaths from mediastinitis, in all of which injuries to the esophagus or the esophagus and trachea had been overlooked.

3 deaths from cerebral anoxia.

2 deaths from aspiration pneumonia, both caused by aspiration of vomitus during anesthesia.

1 death from each of the following causes: cerebral malaria, cerebral embolism, cerebral abscess, phosphorous burns, splenomegaly and jaundice, severe lacerations of the lung, the vagovagal reflex, peritonitis, thrombosis of the pulmonary artery, empyema, right heart failure, massive emphysema, pressure pneumothorax, and multiplicity of wounds.

Post mortem observations.—Post mortem examination was carried out in 78 of the 116 fatalities, the most impressive findings being 12 overlooked injuries, including 3 perforations of the aorta; 3 cardiac injuries, 1 associated with massive pulmonary collapse; 3 injuries of the esophagus, 1 associated with an injury of the trachea; 1 injury of the trachea; and 1 injury of the vena cava. Thoracic surgical teams cared for only 3 of these 12 cases.

Chronology of deaths.—Of the 116 deaths, 9 (7.76 percent) occurred before surgery could be undertaken or on the operating table. Of the remainder, 26 occurred the day of operation, 19 on the first postoperative day, and 9 on the second postoperative day. In other words, something over half (54.3 percent) of the 116 fatalities had occurred by the end of the second postoperative day. All but 10 of the 116 fatalities (91.4 percent) had occurred by the seventh postoperative day.

5TH AUXILIARY SURGICAL GROUP

In the 1,068 combat-incurred wounds of the chest and abdomen treated by surgical teams of the 5th Auxiliary Surgical Group in the European theater in 1944 and 1945 were 374 penetrating and perforating wounds of the chest, with 31 deaths (8.29 percent) and 165 thoracoabdominal wounds, with 39 deaths (23.70 percent). A few of these wounds occurred in civilian casualties, but the analysis does not distinguish them from the injuries in military personnel.

Thoracic Wounds

Basic data.—Of the 374 patients with perforating or penetrating wounds of the chest, 283 were treated in field hospitals and 91 in evacuation hospitals. Field hospitals received twice as many casualties within the first 12 hours after wounding as in the second 12-hour period. Evacuation hospitals received about the same number in each 12-hour period. The timelag for field hospitals averaged 7 hours and for evacuation hospitals, 10 hours.

Of these wounds of the chest, 180 were on the left and 189 on the right; 5 were bilateral. Gunshot caused 193 wounds and shell fragments 181. Penetrating wounds caused by shell fragments were twice as frequent as perforating wounds, and sucking wounds were caused by shell fragments twice as frequently as by gunshot. Sucking wounds were also twice as common in penetrating as in perforating wounds.

Policies of management.—In the European theater, as in the Mediterranean theater, the management of chest wounds progressed through a definite cycle. In the beginning, before surgeons had had much experience with combat-incurred wounds, the general tendency was to be somewhat radical, and there were few patients with chest wounds who did not undergo thoracotomy. When casualties became heavy, however, and there was a large backlog of patients with abdominal and thoracoabdominal wounds, experience showed, as it had in the Mediterranean theater, that casualties with thoracic injuries could be treated satisfactorily by delayed surgery and by less radical procedures.

The following indications for thoracotomy then became regulation:

1. Hemothorax due to active bleeding, with rapid refilling of the pleural cavity after aspiration. The source of bleeding was usually an intercostal artery or the internal mammary artery; the lung itself; or, less often, the heart or some other mediastinal structure. Patients in this group were usually in severe shock on admission and did not respond well to resuscitation.

2. Massive clotted hemothorax that did not lend itself to aspiration. These patients often presented dyspnea, cyanosis, and mediastinal shift. Evacuation of clotted blood and control of bleeding were readily effected through an open thoracotomy, and this method of management became the procedure of choice.

3. Retained foreign bodies 2 cm. or larger in the pulmonary parenchyma or the pleural cavity. The principal indication for removal of these objects was risk of an infected hemothorax or lung abscess. Possible future damage to the lung or to a blood vessel was also considered an acceptable indication.

4. Shattered rib fragments in the lung or pleural cavity or large fragments that had not perforated the pleura. Many surgeons came to believe that bone fragments in the lung were of much more serious consequence than metallic foreign bodies. They were apt to be long and spiky, with irregular edges, and they tended to penetrate the tissues and to forge ahead in them. After a time, bone fragments often became necrotic, and an abscess or an infected hemothorax was a possible consequence. Laceration of a blood vessel was also far more likely from contact with bone fragments than from contact with metallic foreign bodies. The preferable technique of removal was thoracotomy or extrapleural rib resection.

5. Sucking wounds. If intrathoracic damage of any consequence was suspected, thoracotomy was performed. Otherwise, simple debridement and closure was usually all that was necessary.

6. Tension pneumothorax due to an air leak, as in bronchopleural fistula.

After these indications had been set up, the treatment of thoracic casualties became considerably more conservative. Toward the end of the war, however, reports from general hospitals were to the effect that the incidence of infected hemothorax, empyema, and lung abscess was higher when foreign bodies were left in situ, and as a result, more thoracotomies began to be performed. In the 374 wounds of the chest cared for by the

5th Auxiliary Surgical Group, 142 thoracotomies were performed (38.00 percent), with 12 deaths (8.45 percent).

Hemothorax.—Hemothorax was recorded as present in 296 of the 374 perforating or penetrating wounds (79.14 percent) and was stated to be absent in 24 cases. It was probably present in all the cases in which no statements were made about it. Hemothoraces varied in volume from 200 cc. to 2,500 cc. In the absence of other indications for interference, collections up to 300 cc. were left in situ. Larger collections were treated by aspiration, which was repeated as necessary. Air replacement was not employed, and no fluid was used except for a small amount of distilled water necessary to dissolve the penicillin (usually 40,000 units) used intrapleurally. If the chest continued to refill with blood after adequate aspiration, operation was considered to be indicated.

Active intrathoracic bleeding was found at thoracotomy in 50 wounds, 32 of which were caused by shell fragments. In 32 instances, the bleeding was from the lung (in 1 case from an intercostal vessel also), in 16 from an intercostal vessel, and in 2 from the internal mammary artery.

The case fatality rate was apparently related to the volume of the hemothorax. There were 2 deaths in the 49 cases in which the volume ranged up to 500 cc. and 12 in the 78 cases in which it ranged from 2,000 to 2,500 cc.

Tension pneumothorax.—Tension pneumothorax occurred only 32 times, usually in valvelike sucking wounds. Treatment consisted of sealing the wound and emptying the pleural cavity by aspirations. If the collection of air was caused by an actual air leak from the lung, a large needle or stiff catheter was introduced into the pleural cavity via the second anterior interspace, and water-seal drainage was instituted.

Injuries of the lung.—It was the practice to leave small lacerations of the lung unsutured unless they were bleeding. Larger lacerations were repaired.

In one instance, pneumonectomy had to be done for severe lacerations of both the upper and lower lobes. Recovery was uneventful. In another instance, massive intrabronchial hemorrhage occurred after suture of a large laceration and reexpansion of the lung by positive pressure. The patient died before the bleeding could be controlled. Autopsy showed that it came from the laceration and made it clear that a lobectomy should have been done. Both these injuries, however, are exceptions; valid indications for radical surgery for damage to the pulmonary parenchyma were extremely uncommon.

Cardiac wounds.—Cardiac injuries were encountered 4 times in the 374 wounds. Two patients recovered uneventfully, one after suture of a laceration of the left ventricle and one after suture of a laceration of the right atrium and repair of a perforating wound of the lower lobe of the left lung. In the third case, autopsy revealed a shell fragment in the wall of the left ventricle, which had lacerated the descending ramus of the left coronary artery. Roentgenograms had indicated that the object was in the mediastinum. In the fourth case, autopsy revealed a shell fragment 25 by 15 by 10 mm. in the right ventricle. It had entered the superior vena cava and been swept down into the ventricle, lacerating the tricuspid valve in its passage.

Analysis of deaths.—Of the 31 deaths in these 374 injuries, 6 occurred in gunshot wounds and 25 in shell-fragment wounds. Of the fatal wounds, 14 were on the right side and 14 on the left; 3 were bilateral. In one of the bilateral injuries, death occurred suddenly, 7 days after initial wound surgery, from a secondary hemorrhage from a lacerated azygos vein. Another patient developed bilateral pneumothorax and died of anoxia on the third postoperative day.

In 16 cases, death occurred on the operating table or during the first 12 hours after operation, chiefly from shock. In these 16 deaths were 4 caused by blast injuries and 1 caused by a skull fracture.

One fatality represented a serious but quite understandable error in diagnosis. The patient had sustained a penetrating, sucking wound of the left chest. According to the roentgenograms, the stomach seemed to be in the thorax. When, however, the patient

stated that as a boy he had had a left phrenicectomy for tuberculosis, the surgeon's assumption was that the diaphragm was elevated because of the previous operation and that the stomach was below the diaphragm, not above it. Surgery was therefore limited to debridement and closure of the chest wall, without intrathoracic exploration. The patient did not react well from operation and died on the third postoperative day. Autopsy revealed a congenital diaphragmatic hernia of the stomach, which had sustained a perforating wound.

Thoracoabdominal Wounds

Of the 165 casualties with thoracoabdominal wounds treated by the surgeons of the 5th Auxiliary Surgical Group, 4 died before operation could be started or were so obviously moribund that surgery was considered futile. On the other hand, the high case fatality rate from shock in the first 12-hour period after operation shows that surgery was not withheld merely because casualties were poor risks.

Basic data.—Of the 165 thoracoabdominal wounds, 98 were on the left side, of which 27 were fatal; 67 were on the right side, of which 12 were fatal. The difference in the case fatality rates reflects the anatomic location and the vulnerability of the abdominal organs on the two sides.

When there were no thoracic injuries of consequence, the case fatality rates did not differ substantially from the rates in the total series (11 deaths in 62 injuries on the left, 6 deaths in 36 injuries on the right).

In most of the injuries (84 percent), the wound of entrance was in the thorax. In avulsing wounds and through-and-through wounds caused by small arms, it was often impossible to tell whether the course of the missile was from the thorax into the abdomen, or vice versa. In about a quarter of all cases, the thoracoabdominal wounds were complicated by other injuries.

Resuscitation.—Many casualties with both thoracic and thoracoabdominal wounds were brilliant illustrations of what resuscitation can accomplish. One patient with a thoracoabdominal wound, whose blood pressure and pulse could not be obtained when he was first seen, received 17 units of plasma and 6 units of blood in the 10 hours before operation. He entered the operating room with a pulse of 110 and a blood pressure of 115/80 mm. Hg.

On the other hand, shock was sometimes entirely irreversible. In these 165 patients with thoracoabdominal injuries, 47 needed intensive replacement therapy because of their poor condition and the severity of their wounds. Six of the forty-seven received 22 percent of all the blood and 30 percent of all the plasma given to this special group. They were finally deemed operable, but all six died of shock within the first 24 hours after operation.

Pulmonary injuries.—There was no active bleeding in any of the 68 lacerations of the lung in these thoracoabdominal wounds. Suture repair was effected in 20 cases in which a bronchopleural fistula already existed or in which it was thought that one might develop. The other lacerations were left alone. The chest injury usually contributed only a small amount of the blood aspirated from the chest at operation. Most of it came from injuries of the spleen and, in small amounts, from injuries of the stomach and the small intestines.

Surgical approach.—There is no information as to the surgical approach in 25 cases in this series. In 39 wounds, 22 of which were on the left side, the approach was by the thorax. In 44 wounds, separate thoracotomy and laparotomy incisions were used, thoracotomy being the initial procedures in 33 cases and laparotomy in 11 cases. In the remaining 57 cases, 36 of which were on the left side, a laparotomy incision was used and no intrathoracic surgery was done.

If the wounding agent was a shell fragment, thoracotomy was the preferred mode of approach. The reasoning was that because of its larger size and its tumbling, rotating progress, such a missile was likely to create a gaping, sucking wound of the chest and diaphragm, whereas a diaphragmatic wound caused by small arms fire was likely to be sealed over. If the wounding agent was a bullet, the thoracic approach was preferred only

746-941v—65——37

if there was evidence of a cardiac or vascular injury, a severe laceration of the lung, or herniation of abdominal organs through the diaphragm. Otherwise, a laparotomy was thought to be quicker and less shocking than the management of a bullet wound through a transdiaphragmatic incision, which would require enlargement of the diaphragmatic perforation to permit satisfactory exploration and repair.

As a rule, the transdiaphragmatic approach was used on the left side for penetrating wounds of the chest at the level of, or below, the seventh rib if the wound was caused by a projectile whose course was in an almost transverse plane. On the right side, the same indications were used if it was certain that the projectile had not proceeded to the region of the duodenum, right colon, or pancreas, all areas to which approach is blocked by the right lobe and main bulk of the liver. Wounds of the diaphragm located over the extraperitoneal surface of the liver could not be repaired by laparotomy alone; thoracotomy was required for adequate exposure.

The type of abdominal incision was governed by the course of the projectile and, to a lesser extent, by the degree of angulation of the costal margin at the xiphoid process. A subcostal incision in a patient with a wide costal flare provided excellent exposure for repair of the diaphragm and stomach and for exploration of the spleen and kidney, with splenectomy and nephrectomy if necessary. In the asthenic individual, a rectus incision provided good exposure and had the additional advantage of simplifying the placement of a stab wound for exteriorization of an injured colon.

Complications.—In the 75 cases in which the liver was injured, there was no recognized instance of either hepatopleural fistula or bile empyema. Drainage in wounds of the liver was proportionate to the severity of the laceration. Volumes up to 1,500 cc. on the first day were not uncommon, and some wounds were still draining rather large amounts when the patients were evacuated.

Drainage from renal injuries was negligible, and it was concluded that a stab wound to provide for either urine or blood was probably unnecessary unless a major calyx of the renal pelvis was involved.

The chief complications in the 165 thoracoabdominal wounds were as follows:

Two bronchopleural fistulas developed within 24 hours of operation but closed spontaneously after institution of catheter drainage through the second interspace.

Two patients with atelectasis were successfully treated by bronchoscopy. Lesser degrees of atelectasis probably occurred and went undetected. Two patients had lobar pneumonia, in one case associated with an early empyema. This was the only instance of empyema observed before evacuation.

Wound infections were uncommon and usually not serious, but three wound disruptions occurred, one of which was fatal.

Paralytic ileus was present in most cases, sometimes for 4 to 6 days, in extensive injuries of the liver, retroperitoneal hematomas, or large hemoperitoneum.

Analysis of fatalities.—Autopsies were performed in 21 of the 39 deaths in this series. The fatalities were distributed as follows:

Eighteen patients died of shock, fifteen within the first 24 hours after wounding.

Eight patients died of acute pulmonary edema, five with a profuse terminal serohemorrhagic accumulation of fluid in the bronchial tree. In the four cases in which autopsy was performed, the fluid was found to originate in the lung, which was grossly enlarged, heavy, firm, and engorged with blood. Microscopic study revealed edema; acute passive congestion; and red blood cells in the alveoli, as well as areas suggestive of the consolidation of bronchopneumonia. In three of the four cases, the surgeon had no doubt that the cardiovascular system had been overloaded. One of these patients had received a unit of blood and 3 units of plasma before operation, and 4 units of blood and 11 of plasma during the operation. Another had received 1,500 cc. of physiologic salt solution and 2,000 cc. of blood in Alsever's solution over 2½ hours.

Five patients died of pneumonia.

Three patients died of peritonitis, one with pneumonia.

Two deaths occurred from overlooked injuries. One patient succumbed to a rapidly spreading retroperitoneal infection from a missed perforation of the cecum. The other died on the fifth postoperative day, from hemorrhagic shock, after the clot in a missed perforation of the inferior vena cava became dislodged.

One patient with extensive laceration of the liver apparently died from biliary peritonitis.

One death was caused by the migration of a shell fragment, which was dislodged from the inferior vena cava and traveled to the right pulmonary artery, where it acted as an embolus.

One patient suffered an evisceration of a perforated stomach, small intestine, and transverse colon through a 7-by-6-cm. avulsed wound of the left lower chest laterally. After operation, his blood pressure ranged from 80 to 90 mm. Hg, and he was irrational and almost uncontrollable. His condition was presumably due to chronic shock. When renal shutdown was part of the picture, as it was in this case, no therapy was effective.

Whether fat embolism played a part in any of these deaths is not possible to say. None of the microscopic specimens studied in the 21 autopsied cases were positive for fat.

KENNEDY GENERAL HOSPITAL THORACIC SURGERY CENTER

General Considerations

The soundness of policies of early management of combat-incurred chest wounds could be evaluated by a study of the case fatality rates and morbidity rates of the casualties who survived to reach forward hospitals. Similarly, the soundness of policies of management in all oversea hospitals could be evaluated by an analysis of the residual status, and the necessity for further care, of the casualties received later in hospitals in the Zone of Interior. An analysis of the first 500 (of an ultimate 2,350) casualties with combat-incurred chest wounds, received in the thoracic surgery center at Kennedy General Hospital after it had become fully operational in June 1944, provides interesting and useful data of this kind.

Before these data are accepted absolutely, however, two qualifying statements are necessary:

1. It is only fair to emphasize that in a comparative analysis made retrospectively from field medical records and forward hospital records, it was not always easy, or indeed possible, to recognize all the circumstances that confronted surgeons working under combat conditions and that might have influenced their decisions concerning therapy.

2. The figures are frequently overlapping and, in a number of instances, though the records provided no actual proof, it was thought that the incidence of certain injuries and complications was probably higher than the stated figures indicated.

The material for this analysis was obtained by a careful review in each case of the field medical record, the records of previous hospitalizations overseas, the serial roentgenograms taken during the course of treatment, and the condition of the patient on his admission to the chest center. The clinical status of each patient was thus surveyed from the point of vantage of his latest hospitalization and in the light of his previous treatment. As a result, it was possible to make an objective evaluation of the character of the original injury, its initial management, the subsequent therapy, and the complications which followed special wounds and special techniques of management. The composite data permitted the comparative evaluation of surgical versus conservative therapy, forward thoracotomy and the relation of morbidity to its performance or omission, the use or omission of drainage in the closure of chest wounds, and similar routines.

Had a review of the last 500 patients admitted to the center been possible, there is no doubt that, as policies overseas had become stabilized in the light of experience, the outcome of the analysis would have been quite different.

Basic Data

All 500 wounds of the chest included in this survey were penetrating or perforating. Wounds limited to the chest wall very seldom reached thoracic surgery centers in the Zone of Interior. Small arms fire was responsible for only a few injuries, the great majority being caused by bombs and other high explosives.

The original injuries (the figures are sometimes overlapping) included:

211 retained foreign bodies of significant size.

136 sucking wounds.

75 thoracoabdominal wounds or combined thoracic and abdominal wounds.

62 pulmonary lacerations.

45 bronchopleural fistulas.

15 pulmonary contusions.

9 tension pneumothoraces.

8 blast injuries.

4 fractures of the sternum.

3 wounds of the esophagus.

2 wounds of the trachea.

2 wounds of the pericardium.

As far as could be determined from the records, the chest wound was entirely uncomplicated in only 19 cases. Complications which occurred overseas included:

Hemothorax in 455 cases. In 151 of these cases, the hemothorax became infected, and in another 49, it became organized without infection.

Subphrenic abscess in 12 cases.

Pneumonitis and lung abscess about foreign bodies in 11 cases. The same complications developed in the 4 hematomas of the lung in the series.

Hemoptysis secondary to the presence of a foreign body in 8 cases.

Atelectasis in 9 cases.

Pericarditis with effusion in 8 cases.

Infected costal cartilage in 7 cases.

Bronchopneumonia in 5 cases.

Diaphragmatic hernia in 5 cases.

Pulmonary infarction in 3 cases.

Esophageal fistula and paraesophageal abscess in 3 cases.

Pericardial tamponade in 2 cases.

Suppurative pericarditis in 2 cases.

These complications (again, the figures are sometimes overlapping) were managed as follows:

Drainage of empyema in 151 cases, in 46 of which secondary drainage was also necessary.

Thoracentesis in 47 cases.

Decortication in 49 cases.

Drainage of subphrenic abscess in 12 cases.

Pericardial aspiration in 11 cases.

Closure of bronchopleural fistula in 9 cases.

Repair of diaphragmatic hernia in 5 cases.

Resection of ribs for osteochondritis in 4 cases.

Drainage of suppurative pericarditis in 2 cases and drainage to relieve pericardial tamponade in 1 case.

When these 500 patients were received at Kennedy General Hospital, the chest wound was healed in 314 cases (62.8 percent), and no further treatment other than rehabilitation was needed. The remaining 186 patients presented 213 complications, not all of which, as will be pointed out, developed from the original wound. Some of them were the result of the therapy employed. These complications included:

Retained foreign bodies in 131 cases.

Chronic empyema in 82 cases.

Bronchopleural fistula in 36 cases.

Draining sinus in 26 cases.

Hemothorax in 21 cases, in 12 of which the process was of the organized type. These figures should also be evaluated in comparison with the 82 cases of chronic empyema present when these casualties were received at Kennedy General Hospital.

Diaphragmatic hernia in 4 cases.

Esophageal fistula or paraesophageal abscess in 3 cases.

Pericardial effusion in 2 cases.

Special Types of Injuries

Sucking wounds.—The 136 sucking wounds listed in this series were of such a size as to require immediate closure when they were first seen in field or evacuation hospitals. A considerably larger number of patients had similar wounds, but they were so small as to be of no clinical significance. They responded promptly to packing or to debridement and primary closure. It should be noted, however, that infection developed in almost 10 percent of the cases in which the wound was closed primarily without drainage.

In larger sucking wounds, it was the practice to occlude the wound temporarily by packing and to close it permanently later, when debridement was done. Thoracotomy was done at this time in 78 of the 156 cases.

In a number of cases, the chest wound was only partly closed after debridement, and intercostal water-seal drainage was instituted. The records showed that convalescence was smoother in this group of patients than in any other patients with sucking wounds.

In several cases in which a bronchopleural fistula was present and had not been recognized, tension pneumothorax developed after closure of a sucking wound.

Thoracoabdominal wounds.—In this series, 75 of the 500 patients had sustained injuries of the thorax and abdomen, either from a single missile that perforated the diaphragm or from separate perforations of the chest and abdomen. The abdominal organs injured were, in the order of frequency, the liver in 40 cases, the spleen in 16, the stomach in 15, the kidneys in 9, and the small intestine and colon in 7.

All these patients had been treated by prompt surgery, but the order of the procedure depended upon the severity of the chest wound. The chest injury was given first consideration in large sucking wounds, tension pneumothorax, pericardial tamponade, or rapidly developing hemothorax associated with shock and not relieved by conservative therapy. Otherwise, if the cardiorespiratory physiology was not seriously unbalanced, the primary attention was devoted to the abdomen.

The diagnosis of concomitant abdominal injury was frequently difficult when the missile had entered the chest, because in chest wounds in which there was no perforation of the diaphragm, abdominal pain, tenderness, and rigidity were often part of the picture. Urinalysis was always indicated in injuries of the lower chest, to determine whether or not blood was present. Intravenous pyelograms, which were made later in general hospitals, occasionally demonstrated defects in the renal pelvis secondary to injuries of the lower chest.

In the majority of cases in which the injury resulted from a single missile, exploration and the necessary surgery were successfully carried out through a transthoracic approach. When there was doubt concerning the extent and location of the abdominal injury, it was

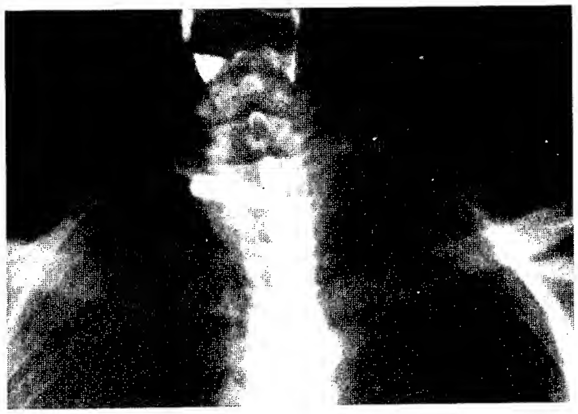

FIGURE 1.—Posteroanterior roentgenogram showing large foreign body in contact with esophagus.

the general policy to use a separate abdominal approach because it permitted more extensive exploration.

The liver apparently tolerated the presence of metallic foreign bodies quite well. At any rate, no abscess resulted from failure to remove them, though biliary drainage followed the injury in a number of cases. When hepatic injuries were explored transpleurally, both the subphrenic space and the pleural space were usually drained. When this precaution was omitted, bile empyema, which occurred in 14 cases, and subphrenic abscess were both possibilities. The most serious instances of bile empyema occurred when the wound was closed without drainage.[3]

Intratracheal anesthesia was employed in all thoracoabdominal injuries, regardless of the surgical approach. The reason is obvious: If a tear of the diaphragm was present, atmospheric air entering from the abdominal incision could cause collapse of the lung on the affected side or even tension pneumothorax.

Tracheoesophageal injuries.—There were only 3 injuries of the cervical esophagus and only 2 injuries of the upper end of the trachea in these 500 patients, but there were 3 similar injuries in the next 300 patients admitted to the Kennedy General Hospital chest center. The thoracic esophagus was not injured in any case in the series studied, even though, in a number of instances, ragged shell fragments were seen by roentgenograms to be lodged in the posterior mediastinum close to it (fig. 1). The high immediate case fatality rate resulting from the hemorrhage and the mediastinal infection commonly associated with injuries of this kind accounts for the small number of patients seen with them in Zone of Interior hospitals.

Three of the five patients with tracheal and esophageal injuries were submitted to immediate tracheotomy, and four had gastrostomies for feeding purposes within 4 to 10 days after wounding. All five developed fistulas of the esophagus associated with abscesses, which had to be drained. When the tracheotomy tubes were removed, from 2 to 3 weeks after operation, none of the patients had any difficulty in breathing.

Two patients with injuries of the esophagus developed strictures which required dilatation, and four of the five with combined injuries of the esophagus and the trachea developed persistent paralysis of the recurrent laryngeal nerve. Because these are extremely serious injuries, the eventual outcome in these cases was regarded as being as satisfactory as possible.

[3] Experience in the Mediterranean theater indicated that there was a significantly higher incidence of bile empyema when the diaphragm was closed with catgut rather than with silk.

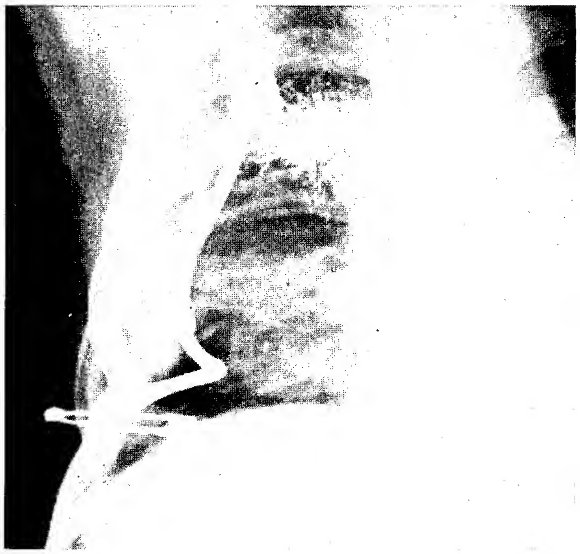

FIGURE 2.—Posteroanterior roentgenogram showing Lipiodol visualization of bronchopleural fistula, narrow empyema track, and drainage site at some distance from fistula.

Bronchopleural fistulas.—The records indicated that 45 of the 500 patients in this series had clinically significant bronchopleural fistulas immediately after sustaining their chest wounds. The chances are that fistulas were also present in a number of other cases but were so small that they required no special treatment and gave rise to no difficulties.

Thirty-six patients had bronchopleural fistulas when they were admitted to the chest center at Kennedy General Hospital, the majority secondary to their original injuries. Eight, however, followed the removal of foreign bodies, and six became evident only after the development of empyema. In other words, not all of these 36 fistulas were part of the original 45 fistulas.

All patients with fistulas observed at the chest center were studied by roentgenograms, after the introduction of iodized oil, to determine the size of the residual empyema space and the anatomic relation of the fistula to the site at which drainage had been instituted after thoracotomy (fig. 2). If the fistula was shown to be at some distance from the cutaneous wound and drainage would have been necessary through a long, narrow, empyematous track, healing was accomplished more rapidly if drainage was established directly over the fistula. When secondary drainage was instituted, exploration often showed that healing had been prevented by the presence of necrotic spicules of rib, bits of clothing, and other foreign bodies embedded in the pulmonary tissue. The removal of these objects and the excision of scar tissue about the fistula were usually followed by prompt healing, though in an occasional case, these measures did not suffice and closure of the fistula had to be accomplished by means of a muscle flap.

Retained Foreign Bodies

As the incidence of immediate and delayed complications shows, the major problems in the management of injuries of the chest concerned retained foreign bodies; hemothorax and pneumothorax; empyema; and the use of thoracotomy, with or without drainage, in forward areas.

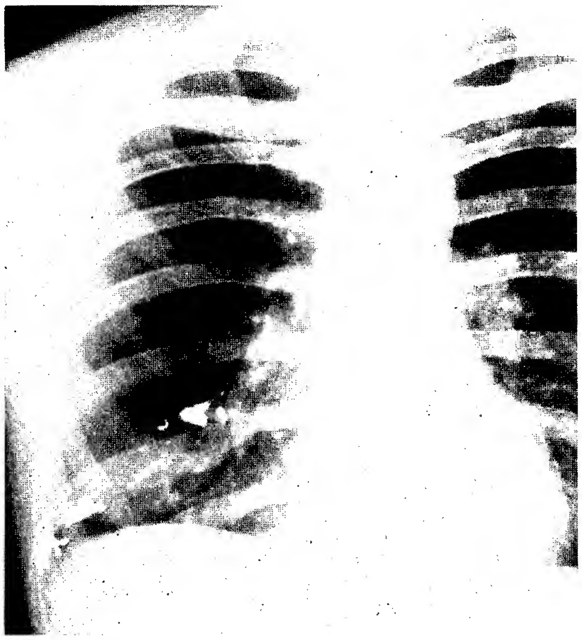

FIGURE 3.—Posteroanterior roentgenogram showing pneumonitis and fibrosis associated with retained foreign bodies.

Management overseas.—Of the 211 patients observed with intrathoracic foreign bodies of considerable size when they were first examined after wounding, 47 underwent removal of the objects at the primary operation and 33, after an interval of several weeks. Many other fragments were noted in other patients when roentgenologic examination was carried out, but their size and location were such as to make them of no clinical significance.

Throughout the war, differences of opinion continued to exist as to the clinical significance of metallic foreign bodies and the indications for their removal. The chief reason for removing them was the possible development of hemorrhage or infection, as well as other complications, but the incidence of these manifestations in this series was not great. In the 164 cases in this series in which the objects were not removed at initial wound surgery, hemoptysis occurred later in 8, draining sinuses developed in 8, lung abscesses in 7, and pneumonitis in 6. In other words, there were no untoward manifestations in 135 of the 164 cases in which the foreign bodies were not removed at initial wound surgery. Moreover, practically all of these complications developed within 2 to 4 weeks after wounding.

In many cases in this series, the removal of the foreign bodies at the initial operation was part of the procedure of debridement, hemostasis, and repair of lacerated lung tissue. In this group, the removal was an incidental step in the operation.

In other instances, however, initial wound surgery was undertaken primarily for the removal of the foreign body. The objects were often hard to locate in newly traumatized tissue, and fresh trauma was created. Bronchopleural fistulas were sometimes created and went unrecognized. If the injury was small, the chest was frequently closed without drainage. As a result of these various circumstances, the incidence of postoperative infection in this group of patients was almost 30 percent.

Generally speaking, infection was most frequent in the cases in which dirt, particles of clothing, and similar debris entered the chest with the foreign body. This extraneous

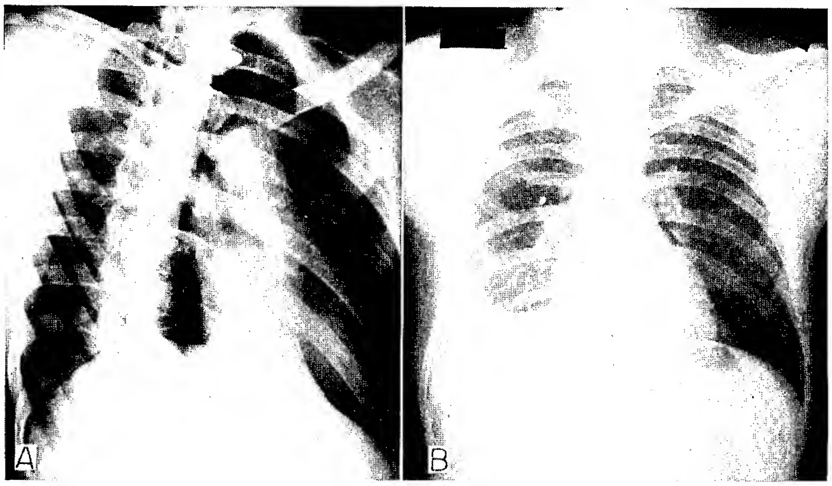

FIGURE 4.—Foreign bodies in contact with large blood vessels. A. Postero-anterior roentgenogram. B. Same.

material was more likely to be the cause of infection than the metallic object itself. Foreign bodies unaccompanied by other debris were usually found at operation, as previous roentgenologic evidence had shown, to be associated with surprisingly little reaction and with no infection. Objects in contact with large blood vessels were practically always well encapsulated in fibrous tissue.

Management in the Zone of Interior.—Of the 131 patients who entered Kennedy General Hospital with roentgenologic evidence of metallic foreign bodies still in situ, only 49 harbored missiles considered of clinical significance because of their size, shape, location, or clinical manifestations. Only 23 of these 49 objects were removed, on the following indications:

1. Large, irregular shell fragments lying within the lung parenchyma were removed without hesitation, particularly if there was an associated pneumonitis or fibrosis (fig. 3).

2. Similarly, no hesitation was felt about removing foreign bodies lying in the mediastinum in contact with the esophagus (fig. 1) or with large blood vessels (fig. 4).

3. Foreign bodies associated with lung abscesses (fig. 5) or empyema were removed at the time the necessary drainage was instituted. Four patients with retained foreign bodies had either pneumonitis or lung abscesses when they were admitted to the center. All four had draining sinuses, and three complained of hemoptysis.

4. In other cases, foreign bodies causing hemoptysis or intercostal pain were removed whenever it could be demonstrated that they were directly responsible for these symptoms (fig. 6). In most such cases, the onset of symptoms occurred shortly after wounding. There was no evidence of infection or other reaction in any case in this series in which roentgenologic examination showed no abnormalities for 2 to 3 months after wounding. This was not, of course, an infallible rule: In one of these cases gross hemoptysis appeared a year after injury.[4]

5. In an occasional case in which operation was not otherwise indicated, the object was removed because of the psychologic factors of fear or pain on the part of the patient.

[4] Attention is called to the patient observed in the Mediterranean theater who required pneumonectomy for a retained foreign body 15 years after wounding.

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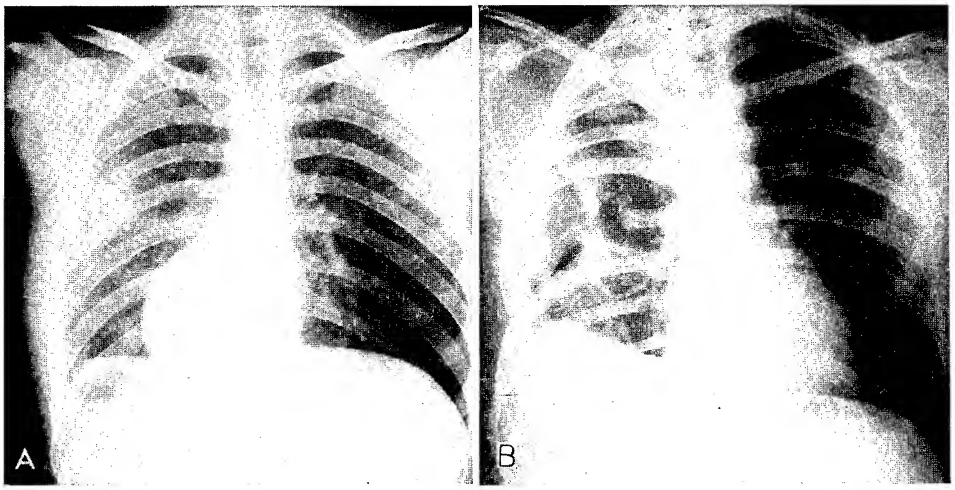

FIGURE 5.—Retained foreign bodies giving rise to infection. A. Posteroanterior roentgenogram showing lung abscess associated with retained object. At operation, clothing and other debris were found in the abscess cavity. B. Posteroanterior roentgenogram showing foreign body partly embedded in lung parenchyma and protruding into empyema cavity.

As the war progressed, the policy at the Kennedy General Hospital thoracic surgery center became increasingly conservative, and foreign bodies were removed only on strict indications. The postwar experience will have to determine the late possibilities for harm of retained foreign bodies and thus establish clear-cut criteria for their removal. It is unfortunate that plans for a formal followup of men with retained shell fragments never came to fruition (vol. I).

Tetanus toxoid was always given before operations for the removal of foreign bodies. Otherwise, the preoperative and postoperative regimen, including the use of penicillin, was the same as for other thoracic operations.

Hemothorax

Management overseas.—Hemothorax was recorded after wounding in 455 of the 500 patients in this series, 91 percent. In many cases, it was present in association with other conditions of serious import, such as sucking wounds, lacerations of the lung tissue, and retained foreign bodies.

The most severely injured patients in this group were submitted to thoracotomy in frontline hospitals, on entirely justifiable indications. In many other cases, however, casualties whose injuries were considerably less severe were also submitted to thoracotomy, on indications that were far from clear cut. The effectiveness of the method of treatment employed in each case is best determined by the presence or absence of infection. The figures are as follows:

Of 74 cases treated expectantly, without any positive therapy, 30 became infected (40.54 percent). In 34 cases, the hemothoraces were small and spontaneous healing occurred. Infection occurred in 6 of the 12 cases of bronchopleural fistula.

Of 156 cases treated by thoracotomy, 75 (48.08 percent) became infected (figs. 7, 8, and 9).

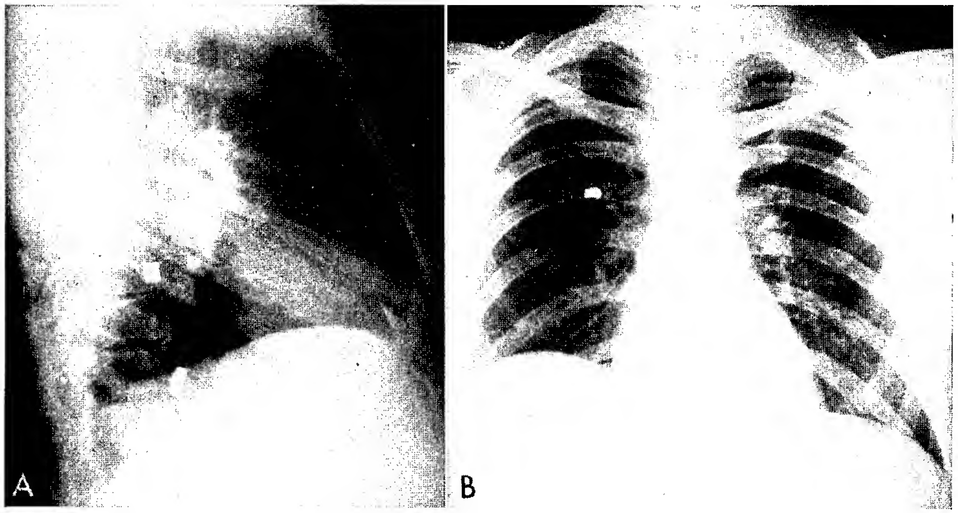

FIGURE 6.—Retained foreign bodies giving rise to symptoms. A. Lateral roentgenogram showing metallic foreign bodies responsible for hemorrhage 1 year after wounding. B. Posteroanterior roentgenogram showing retained metallic foreign body responsible for intercostal pain.

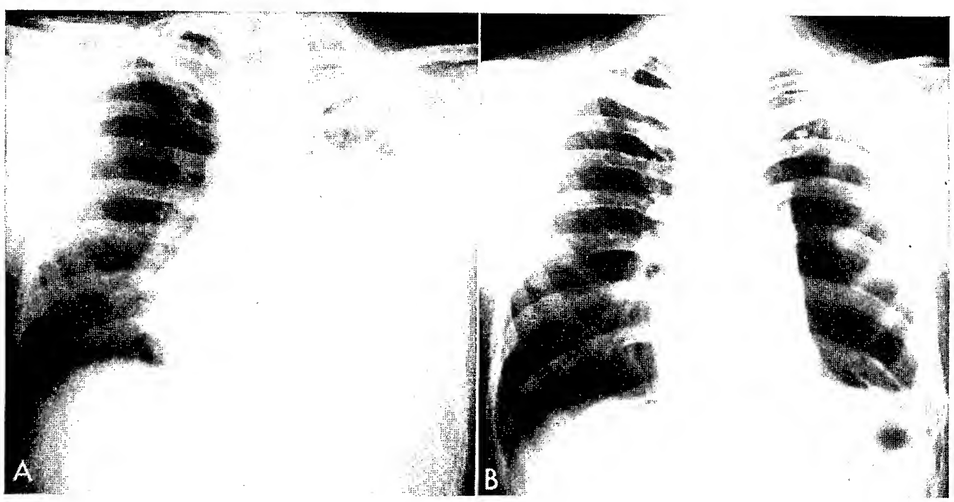

FIGURE 7.—Early thoracotomy without drainage in penetrating bullet wound of chest. Immediate thoracotomy was performed for hemostasis and to remove the bullet, which was found so located in the mediastinum that it could not be removed. The chest was closed without drainage. A. Posteroanterior roentgenogram showing postoperative hemothorax. Note bullet in left apex. The hemothorax later became infected and required open thoracotomy drainage. B. Posteroanterior roentgenogram showing total empyema space.

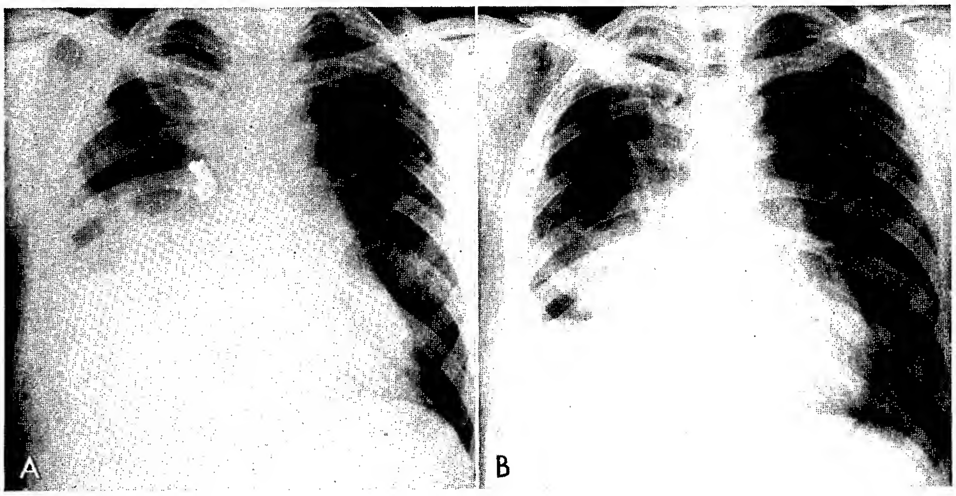

FIGURE 8.—Early thoracotomy without drainage in penetrating shell-fragment wound of right chest. A. Posteroanterior roentgenogram showing retained shell fragment and hemothorax. B. Same, after operation, showing pneumothorax secondary to bronchopleural fistula. The wound was closed without drainage, and the resulting empyema had to be drained on three occasions.

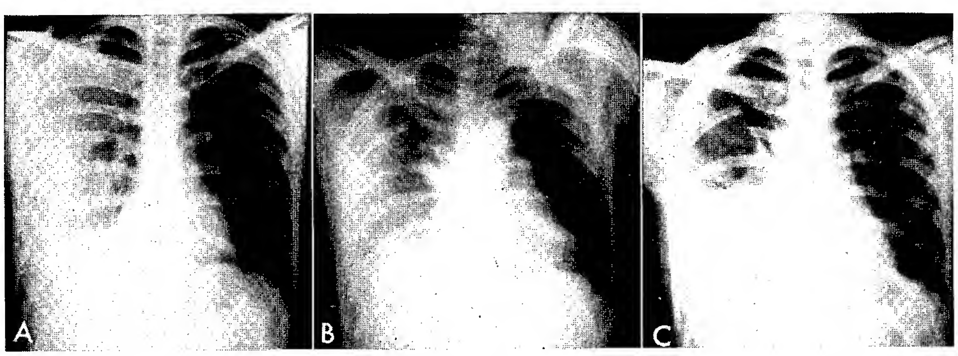

FIGURE 9.—Early thoracotomy without drainage in perforating wound of right chest. A. Posteroanterior roentgenogram showing preoperative hemothorax. B. Same, 2 days after thoracotomy without drainage, which was omitted because the amount of contamination was thought to be minimal. C. Same, showing fluid level in right hemithorax indicative of postoperative empyema.

Of 225 cases treated by repeated thoracenteses, only 38 (16.89 percent) became infected. If the 13 cases are excluded in which aspiration was inadequate and only the 212 properly treated patients are considered, the proportion of infection falls to 11.8 percent. In 11 cases in this group, the chances of good results were reduced by the associated bronchopleural fistulas.

Of the 49 patients whose hemothoraces became organized, 20 had either had no aspiration of the chest or only a single aspiration, and 7 had been aspirated only twice. Nine had been treated by thoracotomy. All of these patients underwent decortication overseas.

The comparative figures leave no doubt of the soundness of thoracentesis as the preferred method of treatment in cases in which immediate operation is not indicated for some reason other than the presence of a hemothorax. The circumstances of military medicine were always in favor of the simplest method of treatment, in this instance thoracentesis, as compared to more complicated methods, in this instance thoracotomy. The necessity for evacuation, the changes of medical personnel from echelon to echelon, and the complicated care required in handling thoracotomy drainage all help to explain the higher incidence of infection when thoracotomy was used in preference to thoracentesis.

Management in the Zone of Interior.—All the cases in which decortication was done at Kennedy General Hospital further confirmed the advantages of this operation (fig. 10). It proved a logical means of developing an easily obtainable cleavage plane between the fibrous encasement of the lung and the adjacent viscera, pleura, pericardium, diaphragm, and chest wall. When the peel was separated from these structures, reexpansion of the lung occurred promptly, the lung tissue herniating through the line of incision as soon as separation was completed.

The experience at this center also confirmed the general opinion that the best results were obtained when the operation was done between 4 and 6 weeks after wounding. If the lung was allowed to remain collapsed for 3 months or more, some fibrosis of the parenchyma frequently took place, and reexpansion after operation was delayed.

There is no doubt that decortication, as it was practiced in World War II, was responsible for many of the good results obtained in casualties with chest wounds (fig. 11) who, in the past, would have become invalids from chronic fibrothorax.

Empyema

Management overseas.—Of the 151 patients who developed empyema in association with their chest injuries, 82 had chronic empyema when they were admitted to the chest center. In 62 of the 151 cases (41.06 percent), the cause of the empyema could be traced directly to the circumstances of the original injury, such as its initial severity, the extensive contamination introduced by the missile, an associated laceration of the lung, or the presence of a bronchopleural fistula.

In the remaining 89 cases, the development of the empyema could be traced wholly or in part to two causes, (1) failure to carry out adequate aspiration of a hemothorax when no other surgery was necessary, and (2) failure to provide postoperative water-seal drainage when surgery had been done.

No patient who had water-seal drainage developed an empyema of any clinical significance, but infection resulted in 31.4 percent of the patients who had been submitted to thoracotomy without postoperative drainage and in 18 percent of those who had had inadequate thoracenteses after operations in which surgical drainage was omitted (figs. 7, 8, and 9). In another 9.4 percent of the cases, the thoracotomy tube had been removed too soon. The analysis of these cases thus suggests that the incidence of empyema in combat-incurred chest injuries could be appreciably reduced if thoracentesis were performed adequately after operation and if adequate water-seal drainage were provided in all cases.

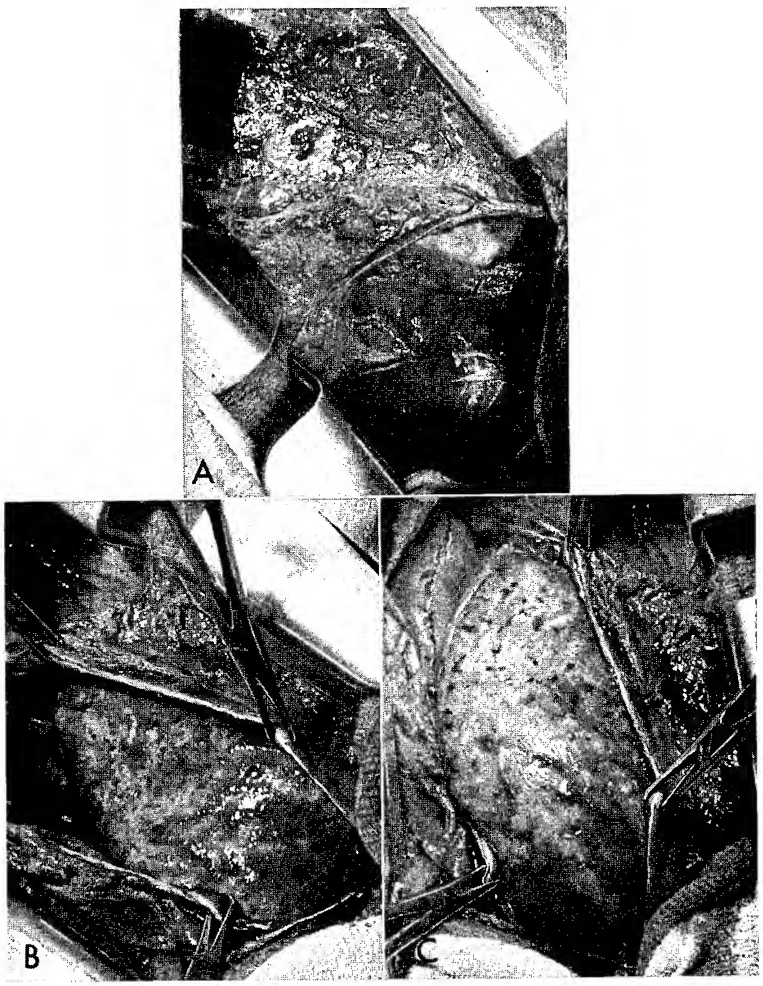

FIGURE 10.—Observations at decortication. A. Organized hemothorax after evacuation of fibrinous mass from pleural space. Note organized fibrin on visceral pleura. B. Easily obtainable plane of cleavage between fibrous encasement and visceral pleura. C. Reexpansion of lung by positive pressure anesthesia after removal of fibrous encasement.

Drainage was carried out overseas in all 151 cases of empyema, on an average of 3½ weeks after the infection was detected. Secondary drainage was necessary in 46 cases In the first months of the war, there was a decided tendency to perform open thoracotomy for infected hemothorax, early in the illness, and total empyema seems to have followed this mode of treatment rather frequently (fig. 12). Later, this policy was almost entirely discontinued, and drainage was deferred until this risk no longer existed.

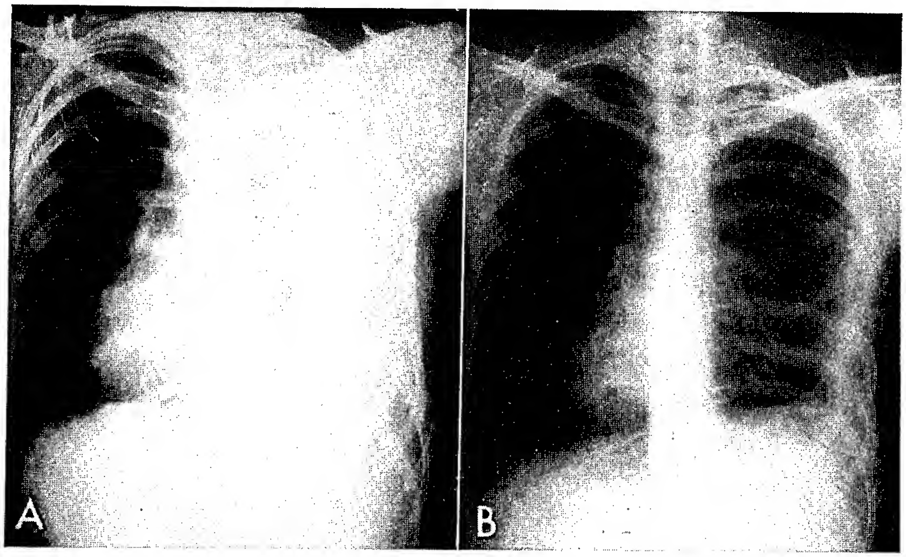

FIGURE 11.—Infected organized hemothorax managed by decortication. A. Postero-anterior roentgenogram before operation. B. Same, showing results of decortication.

Management in the Zone of Interior.—The majority of patients admitted to the chest center with chronic empyema had been adequately drained, and healing was progressing well. If drainage was not adequate, secondary drainage was instituted. Most of the cavities were either small or moderate-size.

Adjunct treatment of chronic empyema usually consisted of continuous suction with 30 to 50 cm. of negative pressure. Breathing exercises and blow bottles were also employed, but the experience was that reexpansion of the lung was more apt to occur, and to occur at a faster rate, when suction was employed. Dakinization of the wound was also employed in a few cases. Other constituents of therapy included repeated transfusions of blood and plasma, high-vitamin diets supplemented by the administration of vitamins by other routes, and general hygienic measures.

As time passed, it was found that empyema secondary to hemothorax could be treated by decortication with practically the same degree of success as could be secured in organized hemothorax without infection. When this method of treatment came into use, it was only an occasional patient with empyema who had to be submitted to thoracoplasty.

Thoracotomy in Forward Hospitals

Many of the cases in this series proved, as has already been intimated, that the mere presence of a penetrating or a perforating wound of the chest did not, in itself, constitute an indication for thoracotomy in a forward hospital. Many operations, in fact, designed to stop hemorrhage or to prevent infection were themselves followed by these and other complications, particularly when the chest was closed without drainage.

Of the 500 patients in this series, 156 were submitted to debridement, with thoracotomy and repair of injured pulmonary tissue, within 24 to 48 hours after wounding. Of these, 6 percent developed organized hemothoraces, and 76 (48.7 percent) developed infection. These patients fared much worse than the 225 patients with hemothorax treated by thoracentesis, in only 16.8 percent of whom was additional treatment necessary because of infection.

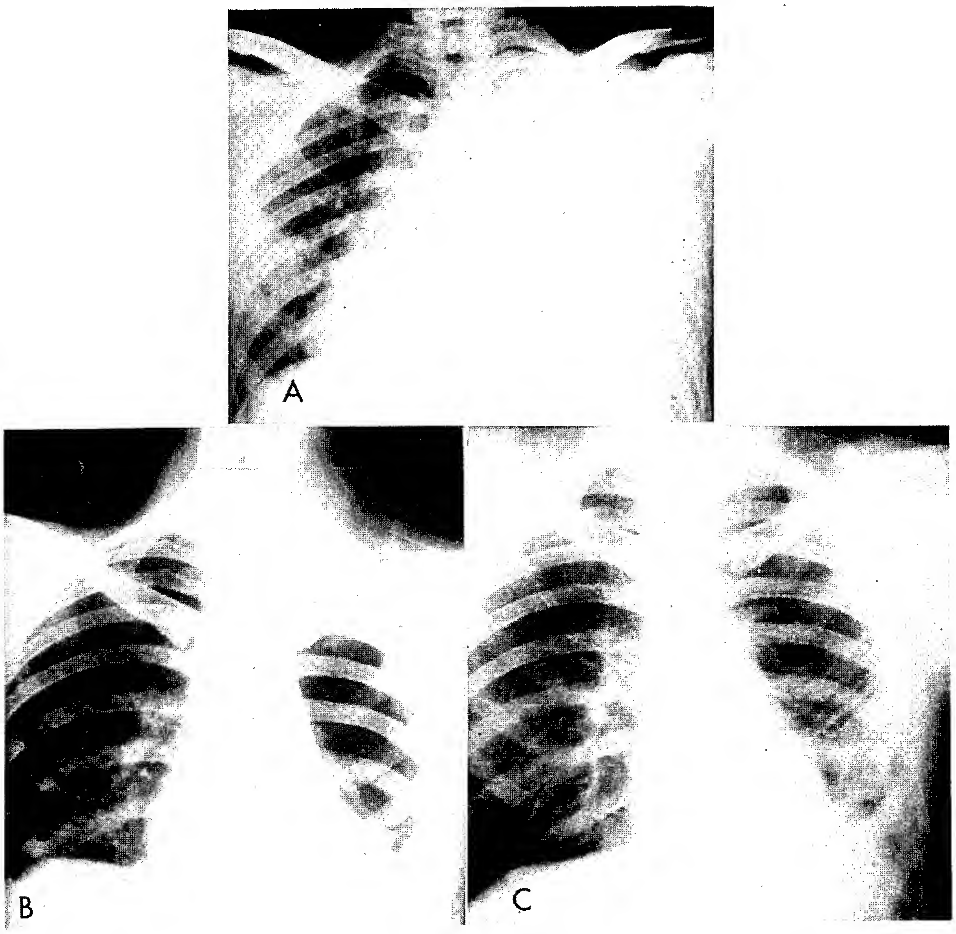

FIGURE 12.—Infected hemothorax and total empyema. A. Posteroanterior roentgenogram showing early infected hemothorax with mediastinal shift. B. Same, showing total residual empyema after early open thoracotomy drainage. C. Same, showing healed chest after continuous suction therapy over 4-month period.

It must be granted that the surgical group included the severest injuries, for which prompt surgery was mandatory and in which complications might have developed if operation had not been done. Furthermore, it was not always easy to determine from records alone the circumstances which led frontline surgeons to follow the courses which they did. Nonetheless, in 66 of the 156 cases in which early thoracotomy was done, the field medical records show no clear-cut indications for the procedure. The majority of the patients in this group presented both hemothoraces and retained foreign bodies, but neither can be considered a valid indication for thoracotomy, and there seems to be no doubt, from the subsequent incidence of infection after the operation, that they would have fared at least as well, and probably better, if they had been treated conservatively.

Since chemotherapy and antibiotic therapy were employed routinely in both the group treated conservatively and the surgical group, a comparison of results from this standpoint would shed no light on the incidence of infection in the two groups. An analysis of the use or omission of drainage in the surgical group, however, produces some useful data:

In addition to the 156 patients submitted to thoracotomy as a primary procedure, 33 other patients underwent the same operation at a later time overseas. In these 189 cases, drainage was instituted in 81 and omitted in 108. In 67 of the 81 drained cases (82.7 percent), healing occurred smoothly, and there was no need for secondary surgery. The patients who became infected were, for the most part, those with the most severe injuries.

In contrast, in 61 of the 108 cases in which drainage was omitted (56.5 percent), secondary operations were required. Furthermore, healing in the undrained group covered an average of 14 weeks, while the average in the drained group was 10 weeks.

The higher incidence of postoperative infection, the greater necessity for secondary surgery, and the longer convalescence all make clear that a thoracotomy closed without drainage achieved desirable results in a much smaller proportion of cases than a thoracotomy supplemented by adequate drainage. The contrast was particularly evident in the 16 patients who were found at primary thoracotomy to have lacerated lung tissue. When the wounds were closed without drainage and operation was not followed by adequate thoracentesis, many of these patients required secondary drainage for infection (fig. 7).

Other considerations also suggested that routine water-seal drainage after thoracotomy in frontline hospitals was a far safer plan than closure without drainage. The conditions under which a surgeon had to care for the wounded in the combat zone usually did not permit him to supervise postoperative care except for a brief period. It was therefore not possible for him to supervise personally the thorough aspiration of a hemothorax, which was essential in all undrained chest cases. Another practical consideration was that water-seal drainage required considerably less time and attention than repeated thoracenteses. This was an important matter in a busy frontline hospital.

As these cases indicated, transportation was not a contraindication to water-seal drainage. While the patient was en route to the rear, the thoracotomy tube could be clamped and the bottle temporarily disconnected, or a flapper type of drain could be used, as was done in a number of these cases in which results were excellent.

Conclusions

An analysis of the first 500 chest injuries received at the thoracic surgery center at Kennedy General Hospital indicated that the oversea management of these cases was generally good. In a Zone of Interior chest center, as might have been expected, mortality is minimal; there were no deaths in this series. Morbidity, however, is a matter of consequence. This study suggests that it can be reduced by the following policies:

1. Thoracentesis should be substituted for operation in the management of hemothorax unless other indications for early surgery exist.

2. Thoracotomy in forward hospitals should be limited to such clear-cut indications as sucking chest wounds, tension pneumothorax, and hemorrhage. The mere existence of a chest wound is not an indication for forward surgery.

3. Thoracentesis should be performed adequately after operation, or adequate water-seal drainage should be instituted.

INDEX [1]

[1] Unless otherwise specified, all entries in this index refer to injuries and diseases of the chest and their management in World War II.

Boothby-Lovelace-Bulbulian mask, 217, 229

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